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Window Thermal Performance Optimization in the Government Built Emirati Family House-Abu Dhabi Emirate.

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This thesis is submitted in partial fulfillment of the requirements for the Master of Science in Architectural Engineering degree

Under the direction of Professor Kheira Anissa Tabet Aoul

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Declaration of Original Work

I, Tareq I A Abuimara, the undersigned, a graduate student at the United Arab Emirates University (UAEU) and the author of the thesis titled "WINDOW THERMAL PERFORMANCE OPTIMIZATION IN THE GOVERNMENT BUILT EMIRATI FAMILY HOUSE-ABU DHABI EMIRATE", hereby solemnly declare that this thesis is an original work done and prepared by me under the guidance of Prof. Kheira A. Tabet Aoul, in the College of Engineering at UAEU. This work has not been previously formed as the basis for the award of any degree, diploma or similar title at this or any other university. The materials borrowed from other sources and included in my thesis have been properly acknowledged.

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ABSTRACT

Presently, the United Arab Emirates (UAE) has one of the world's largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy, primarily used for cooling. In the last three decades, the UAE government launched several housing programs that fit the needs of Emirati beneficiaries while recently targeting also energy efficiency.

This study aims at optimizing the window thermal performance in relation to orientation in a typical house within a representative governmental housing program. Often enough, housing orientation is governed by urban planning layout, where windows rarely show any adapted heat control treatment in relation to orientation despite their significant impact on heat gains under the local extreme hot climate.

This research started with an overview of the historical development of housing programs in the UAE along with "Estidama", the local sustainability framework. Second, a detailed review of optimum window design for heat control is presented. Next, a representative house is selected for investigation based on a detailed review of *Al Falah* governmental housing program, which included master plan layout, housing typology, construction materials and the window's design specifications. The thermal performance of the case study in relation to orientation was evaluated using Home Energy Efficient Design (HEED) software. The results indicate variable annual electricity consumption per orientation with the western orientation leading with 9.7% more than the east, and around 3.0% more than the north and south orientations.

Thereafter, the window thermal optimization process investigated the impact of window's components including glass, frame and external shading devices in relation to each orientation. The best performing components were then combined into two scenarios; the first one included a vinyl frame and double tinted squared Low E glass and the second scenario had Low E glass, vinyl frame and automated slatted blinds. The results indicated a reduction of the total annual energy consumption ranging between around 6% when facing east and 13% when facing west.

More importantly, the optimal window components highlighted similar performance independently from orientation, thus enabling flexibility in housing planning projects while promoting thermal efficiency and energy savings.

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First, I would like to thank Allah who enabled me to complete this study and granted me patience and power until it reached its final form.

Second, this research would not have been possible without the support of many people. Special thanks to my advisor, **Prof. Kheira A. Tabet Aoul**, for her ultimate assistance and support, to **Dr. Rashed K. Al Shaali** for his assistance and support in the experimental part, and **Dr. Khaled Galal** for his assistance in approaching the required data.

Last but not the least, many thanks to my father **Dr. Ismail**, who kept encouraging me and to my wife, **Heba**, who endured with me this hard process, and always offered support and love.

List of Abbreviations

AFRC	Australian Fenestration Rating Council
AL	Air Leakage
BFRC	British Fenestration Rating Council
EPA	Environmental Protection Agency (USA)
HEED	Home Energy Efficient Design Software
IGU	Insulated Glass Unit
MoPW&H	Ministry of Public Works and Housing
NFRC	National Fenestration Rating Council (USA)
SHGC	Solar Heat Gain Coefficient
SZHP	Sheikh Zayed Housing Program
TCDO	Trucial Council Development Office
Tvis	Glass Visual Transmittance
UAE	United Arab Emirates
UPC	Urban Planning Council

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1. CHAPTER ONE: INTRODUCTION

1.1. Background

Presently, designing, constructing and operating energy-efficient buildings is of great relevance at the national and international levels. This became a prime objective for all, since it addresses worldwide issues such as air pollution, climate change, global warming, energy security and resources depletion.

Human activities in general and the building sector in particular are considered as the main drivers behind climate change and global warming (Smith, 2005). This is due to the unprecedented increase of energy consumption which, in turn, increased greenhouse emissions. During the last few decades, the greenhouse emissions have increased globally by 70% (Freidman, 2012). Industry, transportation, and residential sectors in the developed world

burning fossil fuel used in transportation, in industrial operations, and in cooling, heating and lighting of buildings and structures (Freidman, 2012).

The United Arab Emirates (UAE), a small country located in the Arabian Gulf, has experienced unprecedented economic growth in the last 50 years. High revenues were suddenly generated after the discovery of oil in the late sixties. Economic growth has led to a rapid development of the country and improved its people's living standards. As an unavoidable consequence, consumption of natural resources, such as energy, water, fuel, wood, fiber, timber, and food has increased significantly (Clair, 2009). These extreme rates of consumption have appointed UAE as a country with the highest per capita ecological footprint in the world (Heroes of the UAE1, 2013). Further analysis of the UAE ecological footprint indicates that households have the greatest impact in this substantial ecological footprint (Figure 1.1)

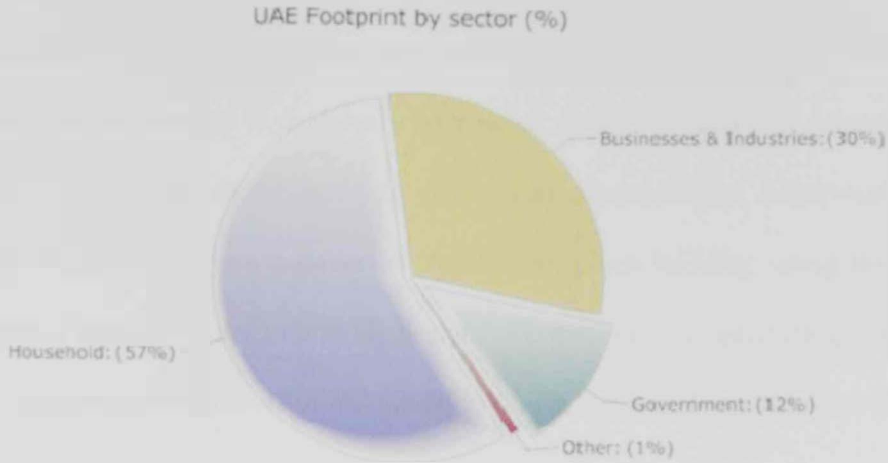

Figure 1.1: UAE Ecological Footprint per Sector (Heroes of the UAE, 2013)

Since its establishment in the early seventies, the government of the UAE has been acting as the main housing provider by launching mega low-cost housing projects across the country. These housing programs came in form of large numbers of detached houses with all related services. This government-led expansion of housing projects during the last few decades has increased the demand on energy resources for cooling, lighting, and operating buildings.

Detached houses feature a large exposed envelop that receives a significant amount of solar radiation. Hence, it can be the most energy demanding housing type and therefore detached building envelop is being considered as an important determinant of building energy efficiency.

Windows are critical components in the building envelop efficiency and responsiveness to the climate. They are generally made of glass of which some types can transmit up to 75% or more of the incident solar radiation (ASHRAE, 2005). Adapting window design to the climate can reduce demand on energy in housing.

1.2. Problem Statement

Sustainability and energy savings are nowadays considered a serious national concern that the country is decisively addressing. In this context, the government of Abu Dhabi has established its own local sustainability framework i.e. ESTIDAMA. Similar to a number of well-known green building rating systems, Estidama's main goals are to provide design, construction and operation guidelines that guarantee a certain level of sustainability in buildings and communities (UPC, 2010).

The government of Abu Dhabi, a main housing provider for its citizens, has launched the *Emirati Housing Program*. This program aims at providing 13,000 houses until 2017 in the form of residential communities and neighborhoods in the cities of Abu Dhabi, Al Ain, and Al Gharbia (UPC[3], 2011). These projects aim at the accommodation of cultural values and environmental adaptation through the design and construction of modern, high quality, sustainable homes that reflect Emirati heritage and traditions, as well as meeting Estidama requirements (UPC, 2011).

Al Falah Community, the case study of this research, is one of the Emirati Family Housing Program. It is located near the city of Abu Dhabi and comprises 4800 detached houses (Aldar, 2009). A survey of Al Falah houses indicates a compliance with Estidama requirements limited to walls, roof insulation and low flow water fixtures.

Window design and specifications remains an arbitrary choice despite the well-recognized windows critical impact in terms of thermal gain. Despite the tremendous development in glass, frames with improved thermal performance under the drive of energy efficiency and sustainability, window design however remains an aesthetical consideration that often is not adapted to the context. Typical floor plans show that window openings are invariably implemented in various orientations, thus restraining adaptation of window design and treatment to the context. This imposes additional thermal burdens in houses that are inappropriately oriented and consequently increases energy consumption.

1.3. Objectives of the Study and Methodology

This study aims at optimizing the window thermal performance in relation to orientation in a typical house within a representative governmental housing program.

For this purpose, the work is designed to firstly; review the government-built Emirati family house programs by analyzing their typology and environmental objectives in order to determine a representative typology. Secondly, to survey window design characteristics in one representative housing program; Al Falah Community. Then, the impact of orientation will be addressed through an experimental evaluation of the thermal performance of the existing design through simulation. Finally, a multi-level optimization process of the window parameters will be explored.

The main target of this research is to find a window specification that provides an optimal thermal performance independently from building orientation.

1.4. Thesis Organization

This work is structured in seven chapters and may be best summarized as follows: The research is initiated by an introduction in Chapter One, where the problem is identified and the main objective is outlined. Chapter Two presents an extensive review of the historical development of housing and governmental housing programs in particular in the UAE, along with the increasing concern for environmental issues and energy conservation. The importance of green design and window optimization is reviewed in Chapter Three to sustain the window optimization process. Chapter Four focuses on the case study by providing a detailed description of Al Falah community including its general planning, housing typology, construction, and window characteristics.

Chapter Five is dedicated to the presentation of the experimental work and procedures followed by testing the case study existing conditions. Chapter Six presents the optimization process of window design. Chapter Seven concludes the work with a series of recommendations.

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2. CHAPTER TWO: HOUSING IN THE UNITED ARAB EMIRATES

2.1. Housing in the UAE; Historical Background

Prior to the discovery of oil in the 1960's, the United Arab Emirates was one of the poorest areas in the world, with an economy based on fishing, agriculture, trade, and pearl fishing (Peck, 1986). However the discovery of oil in 1960's, transformed the UAE into one of the highest per capita income countries in the world.

2.1.1. Pre-Oil Era Housing; Prior to the 1960's

Before the discovery of oil; UAE's present cities were merely small human settlements located at the intersections of trade roads. Abu Dhabi was a small village inhabited by coastal tribes, while Al Ain was an oasis settlement rich in water and palm trees. On the other hand; because of its location at the entrance of navigable creek, Dubai was comparatively, an outstanding trade center with India for goods and pearls.

The UAE vernacular architecture within these settlements was the result of a combination of factors including a harsh climate, well-established people customs and traditions, as well as the availability of construction material (Sheikh Mohammed Bin Rashed, 2013).

The climate was a determining factor in shaping the traditional architecture. The prevailing harsh climate imposed the adoption of climate responsive building and construction methods. For this purpose buildings used to be laid close to each other in order to minimize the exposed surface to the solar radiation. The allocation of houses used to be along alleys called *Sikka* oriented to the north- south direction to allow air circulation. The Sikka is shaded during the whole day by houses located on both sides (Sheikh Mohammed Bin Rashed, 2013). Rooms were located around courtyards with inward openings. House entrances were designed in such a way to achieve privacy, an important component of the local people's customs and religious belief.

Air catchers known locally as (*Barajil*) were the main distinctive element of the local vernacular architecture. Air catchers are towers rising above the building roof with four openings that are oriented towards the prevailing wind. Air catchers function as effective natural ventilation devices.

In old UAE cities; there were several types of buildings. For defense purposes, Citadels and forts were built of stones with thick walls and towers at each corner. Mosques were smaller than forts, with rectangular floor plans, built of stone walls and located near residential areas.

By contrast, houses followed several types and shapes depending on the owner's wealth. Tents were the main shelters during winter season for the local nomadic groups the Bedouins. A typical tent was made of hair and animal hides. Arish is another type of houses used solely during the summer season. It is a shelter that made of palm tree leaves consists of two spaces; one for living and sleeping and the other for cooking (Mahgoub, 1999).

Permanent houses were owned by richer people and were made of stone and bricks. Winter houses were located near the coastline while summer ones were at palm trees farms (Mahgoub, 1999).

The home of Sheik Saeed Al Maktoom, the ruler of Dubai from 1912 to 1958, is often considered as a representative building for permanent houses that were built about a hundred years ago. It was renovated in 1986 and renamed *Dubai Museum*.

The house consists of 30 rooms, 20 verandas, 10 bathrooms, and 3 courtyards. The house is divided into two stories with six independent living zones. It was constructed using coral stone, lime and plaster.

The house has four air catchers or Barajils that are kept open during summer for natural ventilation, and closed during winter (Mahgoub, 1999). Windows are small in size, recessed with views only to the courtyards to provide privacy and respond to climate.

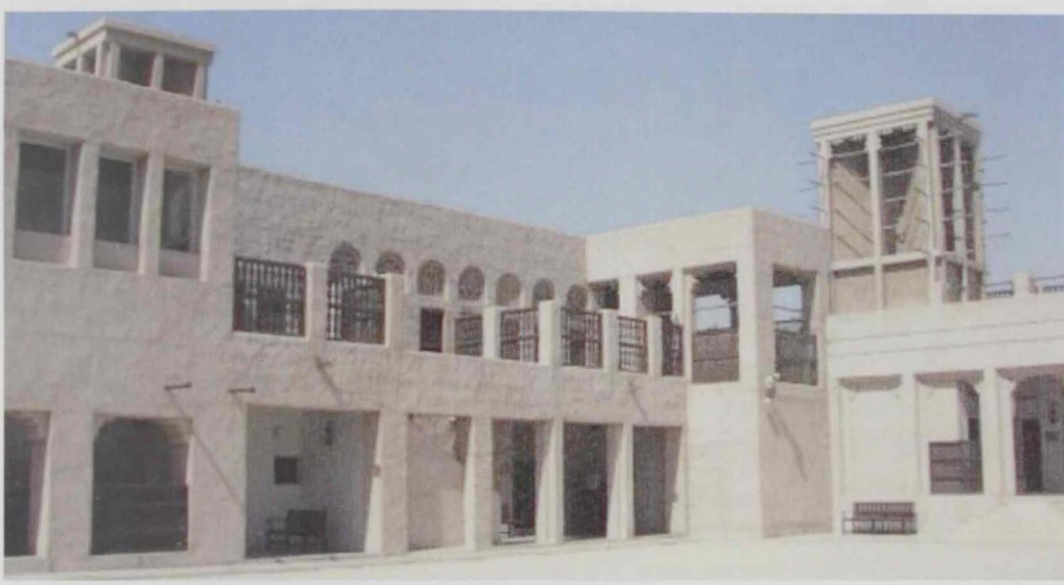

Figure 2.1: Sheikh Saeed Al Maktoom House in Dubai (Source: Stay, 2013)

2.1.2. Housing during the Oil Era, from the 1960s Onward

The discovery of oil in the sixties has led to rapid economic growth in the UAE, which resulted in dramatic changes in lifestyle and provided a high level of prosperity to its citizens. The oil crisis in the early seventies created a huge amount of oil revenues which enabled the government to provide free housing for its own citizens.

This wealth also introduced modern architecture in the region. the one that fully relies on active systems and neglects the passive adaption of design to the climate (Al-Sallal et al, 2012). New types of residential buildings emerged to housing including detached houses (villas), emerged along multi-story building. and residential towers. During that particular era: government used different approaches from providing turn- key. distributing land and offering attractive housing loans houses to its citizens.

The next sections provide a detailed description of the development of governmental housing programs and the development of houses in terms of size and typology.

2.2. Governmental Housing Programs

During the era that followed the discovery of oil; the level of governmental intervention in the housing sector also experienced an inner process of development and created various versions of housing programs. The following section presents the progression of the housing programs within the last several decades.

2.2.1. Early Housing Programs

The first housing program was launched by the *Trucial Council Development Office's* (TCDO) in the country. The program started in 1965-1966 and aimed at providing low-cost two bedroom houses. The houses were designed by British and Indian engineers. This housing program was located in the Fujairah. Ras al Khaimah, Ajman and Umm al Qaiwain Emirates (Al Mansouri. 1997).

Another housing program was established in Abu Dhabi in 1966. This program aimed to provide four thousand units. The underlying objective was to improve the quality of life of the citizens. These houses were built of concrete and provided with electricity and water facilities (Sadik and Snavely, 1972).

In the seventies Dubai and Sharjah launched their own low-cost housing programs with all related services (Al Mansoori. 1997).

In the northern emirates which lack oil revenues the sector of services including housing remained totally dependent on the federal institutions. The Ministry of Public Works and Housing lead this process (Ministry of PW&H. 1995).

2.2.2. Recent Housing Programs

In 1999, the Sheik Zayed Housing Program (SZHP) was launched. This program was established as a response to a growing population comforted by a substantial economic growth. The main objective of this housing program is to provide suitable housing for deserving UAE national families (SZHP[1]. 2012). Sheikh Zayed program was able to deliver 18204 houses between years 1999 and 2008 (SZHP[2], 2008). The SZHP offers zero-interest housing grants. non-refundable housing and government-subsidized housing (Abu Dhabi Gov. 2013).

SZHP's homes include several typologies that varied from one story houses to two story houses with differing sizes and layouts. Some units are provided with flexibility to expand (SZHP. 2013).

In Dubai. the Mohamed Bin Rashid Housing Establishment has its ongoing housing programs and projects. Similarly. its services include free governmental houses. individual residential plots. renovation/addition to existing structures.

attractive housing loans for new construction as well as for maintenance and renovation (Dubai Government, 2012).

Along the same line, the Emirati Housing Program is the most recent housing program in the UAE. The program was launched by the Abu Dhabi Urban Planning Council (UPC) in 2009. It aims at providing world class housing in the Emirate of Abu Dhabi for the local families. This program aims at providing 13,000 houses for Emirati families over the coming few years in the cities of Abu Dhabi, Al Ain and Al Gharbia (UPC[3], 2011). This program strongly targets the accommodation of cultural values and environmental adaptation through the design and construction of modern high quality, sustainable homes that built on Emirati heritage and traditions, as well as meet the local sustainability framework ESTIDAMA (UPC[3], 2011). The 13,000 houses vary in architectural style, and size. 3, 4 and 5-bedroom villas are proposed in the program (Aldar, 2009).

2.2.3. Housing Typology Development

Housing has experienced a dramatic development during the last few decades as a result of dynamic economic growth. The change occurred in both areas including prototype and style. This section traces changes to housing prototype since the early governmental involvement.

Until the 1950s, housing responsibility was of the private citizens. Most inhabitants were poor and relied on their own resources and that of the extended family to build their own homes. Merchants and rulers had their homes built by specialized builders (Dostal, 1983).

Originally, the greatest majority of houses were built with date tree products. Depending on their location, they were commonly called "*Barasti*", "*Arish*" or "khaimah"(Kay and Zandi, 1991). Houses had at least one room and were surrounded by a fence made from branches of date tree for privacy (Kay and Zandi, 1991). On the other hand rulers and rich merchants used to get their houses built from coral stone, mud bricks and mangrove wood (Kay and Zandi, 1991). Interestingly enough, all of these traditional constructions relied on locally available materials (Kanoo, 1971).

In the late 1950's and early 1960's new types of housing started to emerge in the market, like the detached houses and multi-story building (Al Mansoori, 1997). These new types appeared as a result of hiring engineers, architects, and planners from outside the country, bringing along new design concepts, construction methods and materials like cement, reinforcement steel, and wood.

In the early seventies and alongside an economic expansion and considerable revenues generated from oil, the government started to expand the development of

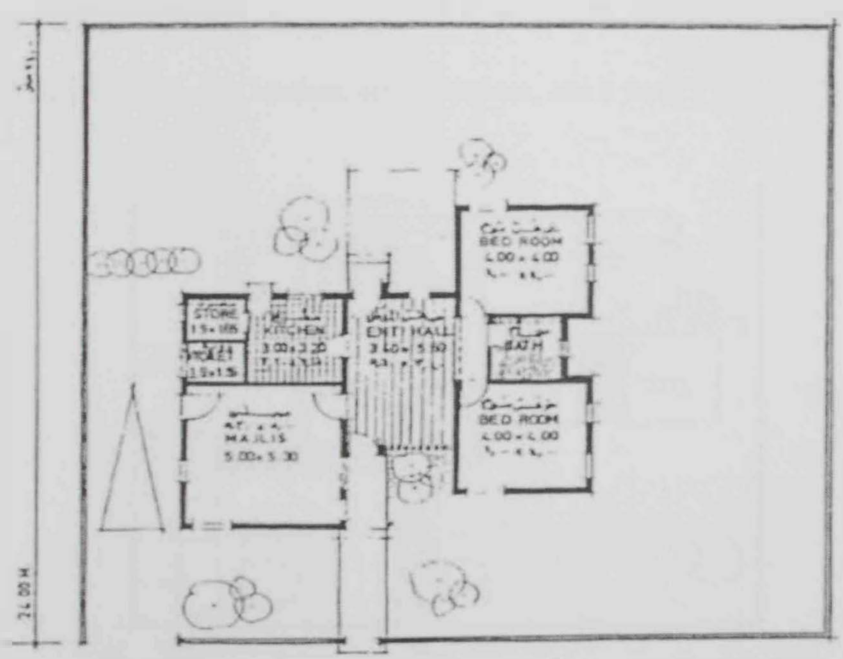

Figure 2.2: Floor Plan for Low-Cost House in 1970's (Cited in Al Mansoori, 1997)

Source: (Ministry of PW&H, 1988)

low-cost housing to be given free to the citizens. The early housing programs targeted settling Bedouins who formed a large portion of the country's population (Ministry of Information. 1977). These houses, as shown in figure 2.2. consisted of two bedrooms; a *majlis* (A guest room), a large hall, a kitchen, and bathroom for a total area of 108-116m2 (Al Mansoori, 1997). Full services such as electricity. water, sewerage, roads, educational and health care facilities were largely provided in these new communities.

The housing model from the seventies was heavily blamed for not being suitable to local families and their lifestyle. Therefore, improvements were brought upon in the following decade. The improvement involved an increase in the built up area to $160m^2$. The number of bedrooms became three and the majlis and kitchen were isolated from the sleeping areas. The housing prototype improvement continued, and the built up area was even brought to 193-203 m^2 and then to $244m^2$ (Ministry of PW&H. 1981). In the 1990's, the size of the house was increased to be $340m^2$ with an average of 4 bedrooms, one hall or in some cases two, a majlis, dining room, 5 bath/toilet rooms, kitchen, servant rooms, and a store.

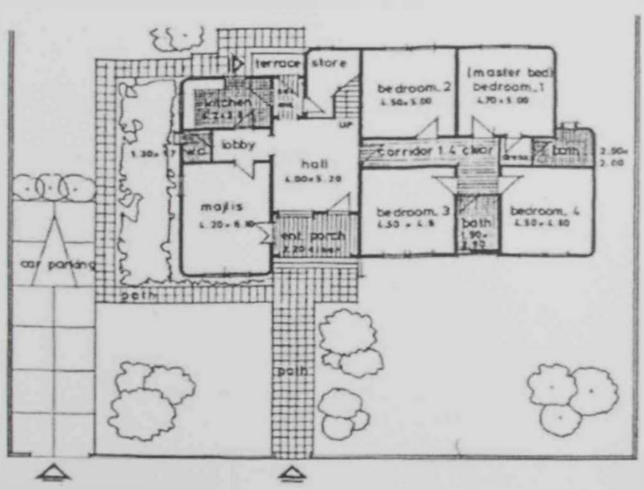

Figure 2.3: Floor Plan of Sample Houses in 1980's Source: Ministry of PW&H 1988 (Cited in Al Mansoori, 1997)

In parallel, the government established other housing programs that targeted other income groups. Local governments led the way especially in Abu Dhabi, Dubai, and Sharjah. These programs consisted in interest-free housing loans, free land and services land grants to whomever can afford to get his home built (Al Mansoori, 1997).

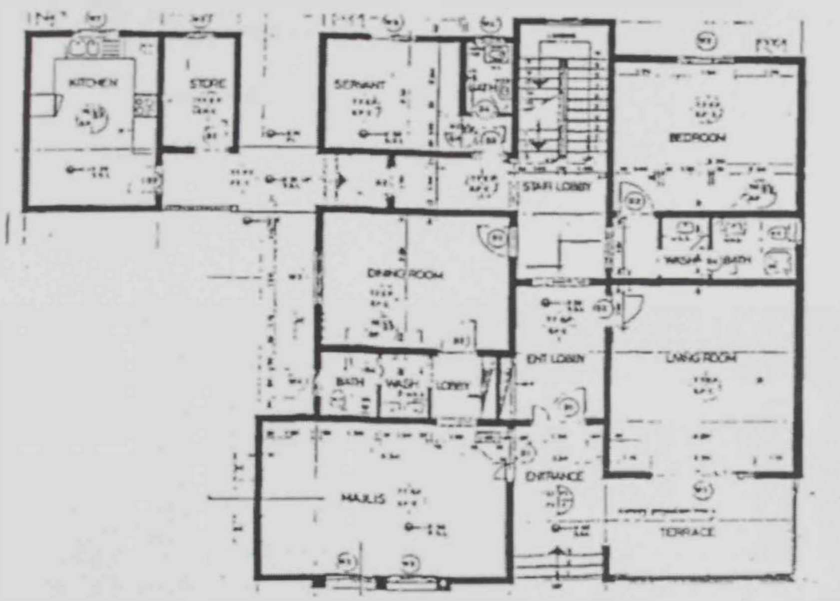

Figure 2.4: Ground Floor Plan of a House in 1990's

Source: Ministry of PW&H (Cited in Al Mansoori, 1997)

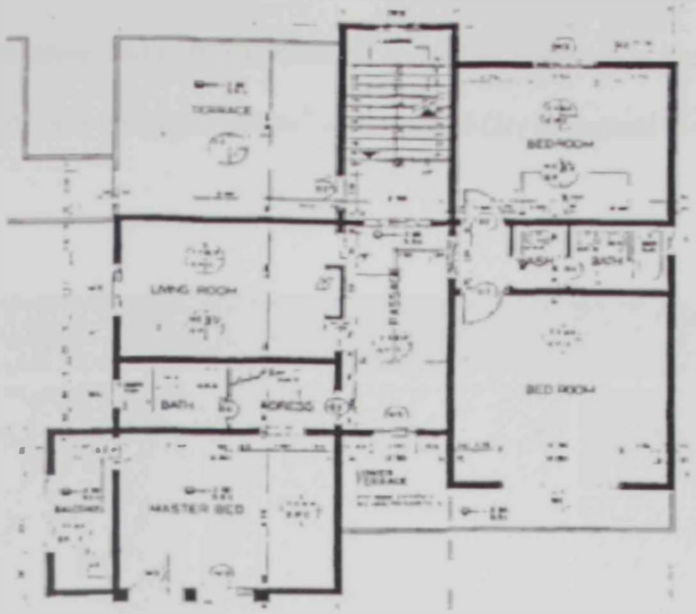

Figure 2.5: First Floor Plan of a House in 1990's.

Source: Ministry of PW&H (Cited in Al Mansoori, 1997)

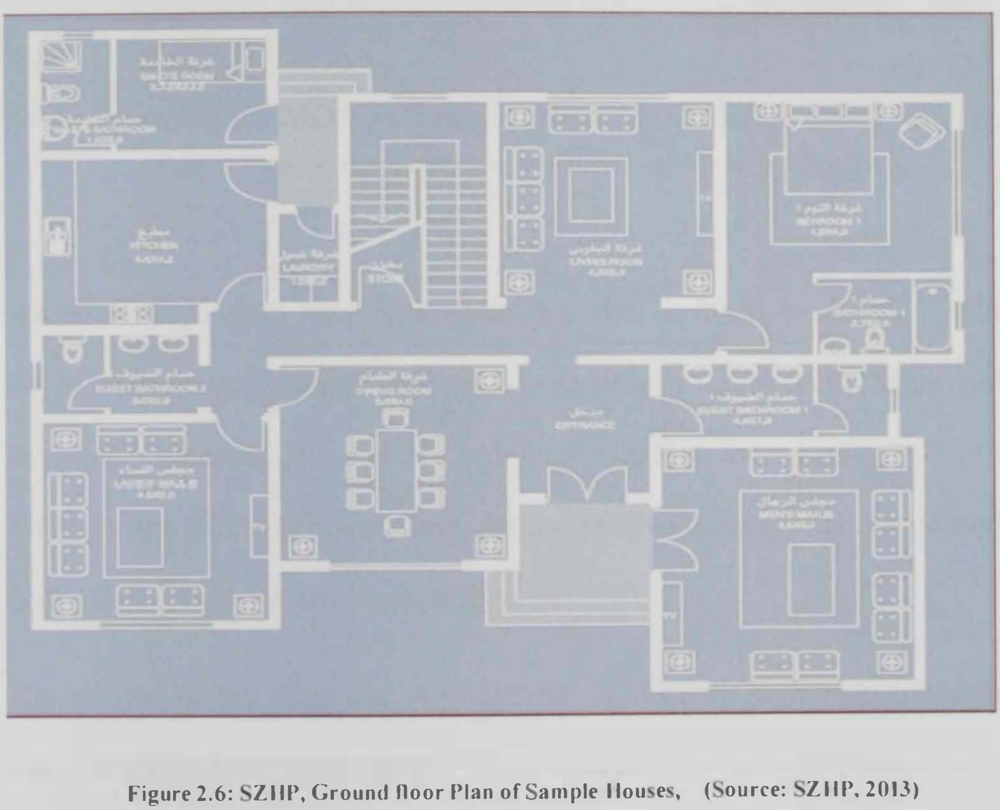

Figure 2.6: SZHP, Ground floor Plan of Sample Houses, (Source: SZHP, 2013)

During the last two decades houses have experienced a substantial increase in size, layout modification and new architectural style. For instance, in the late 1990's, a typical SZHP home averaged 408 m^2 with a possibility to expand to 456 m^2.

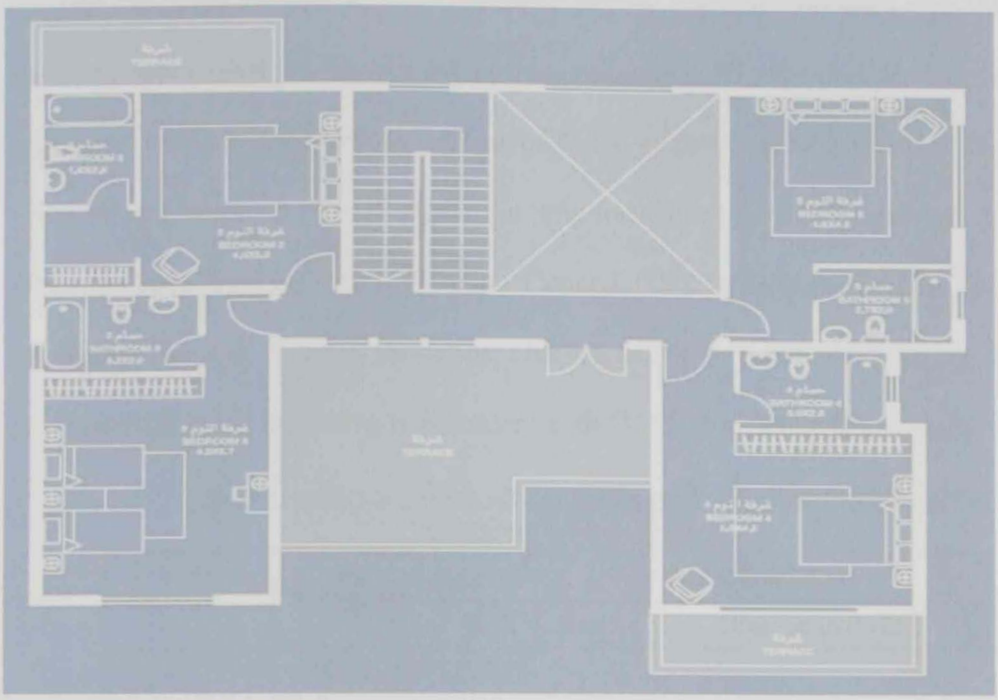

Figure 2.7: SZHP, First Floor Plan, Sample of Houses (Source: SZHP, 2013)

Houses in the Emirati Housing Program launched in 2011, by the UPC in Abu Dhabi, have several architectural styles with different floor areas. Villas varied from three bedrooms, four and five bedrooms with floor areas totaling 293.15 m^2, 356.96 m^2 and 418.38m^2 respectively. All the villas of the same size shared similar floor plan but varied in architectural style.

The review of the historical development of housing highlights tremendous transformation of housing in terms of size, material used and architectural style. It moved from housing that depends on climate responsive strategies and utilization of local material to a one that is constructed using imported material and operated by active systems. These choices have contributed strongly in creating the large ecological footprint of the country.

2.2.4. Environmental Measures

Despite the harsh climate and the excessive energy consumption rates, the UAE has not implemented any energy saving regulation until this last decade. The first regulation was introduced in the Emirate of Dubai in 2003, while a period of eight years passed before a similar regulation was introduced in the Emirate of Abu Dhabi in 2011 by The Urban Planning Council (UPC) (AlNaqbi, 2012). These regulations impose specific insulation characteristics in buildings. Figure 2.8 presents the thermal insulation requirement in the UAE at different timeframes.

TABLE I: THERMAL INSULATION REQUIREMENTS IN THE UAE AT DIFFERENT TIMEFRAMES

Emirate	Timeframe	U-value (W/m^2 K)		
		Wall	Roof	Glazing (SHGC*)
Abu Dhabi	2003-2010	NA		
	2011**-	0.32	0.14	2.2 (0.4)
Dubai	2003-2010	0.57	0.44	3.28 (NA)
	2011-	0.57	0.3	2.1 (0.25)
Sharjah	2003-2010	0.57	0.44	3.18 (0.43) for w/w*** <40% 2.18 (0.43) for w/w >40%
	2011-	No change from the 2003 requirements		

* Solar Heat Gain Coefficient

** Requirements for 1 Pearl (mandatory) rating

*** Window/Wall ratio

Figure 2.8:Building Thermal Insulation Requirement in UAE (AlNaqbi, 2012)

Interestingly, while a window to wall ratio is considered in one emirate (Sharjah), there is no indication of any specific requirement for windows in housing. As a matter of fact, windows were manufactured with a single clear glass and a

traditional aluminum frame regardless of the well-known poor insulating properties of such traditional windows.

2.3. Housing and Climatic Challenge

The location of the UAE brings a serious challenge to both housing designers and later on to the house owners. This design challenge lays in adapting the intended design to the extreme hot climate, while the owner challenge lays in the running cost of these houses.

The UAE lies in the arid tropical zone extending across Asia and North Africa. Climatic conditions in the area are strongly influenced by the Indian Ocean. The high temperatures in summer are always accompanied by high humidity along the coast. The average rainfall is low at less than 6.5 centimeters annually, more than half of which falls in December and January (Cited in Al-Shaali, 2002). The climate of the UAE is simply called 'tropical semi desert and desert climate 'in the east, and 'semi deserts and desert climates' in the west (Troll & Paffen, 1980).

Nowadays modern houses prototypes which were mostly imported from outside the region have almost shown no adaption to the climate or local culture (Al-Sallal, 2012).

The residential sector accounts for a significant amount of newly constructed houses (65% According to National Statistics Center (Abu Dhabi Government, 2010). This domination and dependency on active cooling systems resulted in excessive energy consumption for cooling, that equaled 39% of the total electricity consumption (RSB, 2007).

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In 2003 and for the first time in the UAE; the Government of Dubai adopted regulations that imposes insulation and glazing requirements for new buildings that lead to energy saving (AlNaqbi et al. 2012)

On the other hand the Government of Abu Dhabi and its Urban Planning Council established ESTIDAMA; its sustainability framework. ESTIDAMA aims at achieving sustainability and energy conservation in buildings through providing guidelines for newly constructed buildings (AlNaqbi et al. 2012).

2.4. Conclusion

The transformation of the UAE from a poor country made of nomadic tribes to a highly urbanized one had a great impact on the development of housing. The rapid economic growth driven by oil revenues enabled the government to play a major role in providing housing for its citizens. On the other hand it has changed people lifestyle, improved the quality of life and increased their housing requirements.

During the decades following the discovery of oil; the government has been playing the role of a housing provider through successive housing programs aimed at enabling citizens to own their houses. In parallel, housing prototypes experienced noticeable change in size and style, but limited materials and windows specifications to mitigate the impact of the extreme hot climate.

The following chapter will present a review of window design principles for solar control in buildings.

3. CHAPTER THREE: RESIDENTIAL WINDOWS IN HOT CLIMATE; DESIGN FOR COMFORT

3.1. Introduction

It is widely accepted that as stated by The Berkeley National Laboratory (LBNL), s that 25-30% of cooling and heating energy is due to windows (Cardomy & Haglund, 2012). Hence, upgrading residential windows is of great importance for energy savings. Heat gain through poorly specified windows can impose additional thermal burdens and consequently increase cooling loads in weather dominant building such as detached houses (Lyons, 2001).

Traditionally, single clear-glazed windows have been considered as the weakest point of the building envelop as its resistance to heat gain is ten times less than an insulated wall (Lyons, 2001). However, recent advanced glazing systems claim the possibility to benefit from daylight and view without affecting the indoor level of comfort.

This chapter attempts to review and investigate the role of the window in general and aim to identify the optimum thermal properties and performance in a hot harsh climate. Moreover; it proposes window design guidelines for solar control.

3.2. Role of the Window

Windows plays a major role in buildings. This role is subdivided to physical role and psychological role (Tabet Aoul, 2012). The psychological role includes enhancing occupants' well-being, and health through providing view, sense of time and weather. On the other hand the windows' physical role includes mainly visual communication between indoor and outdoor, and provision of daylight (Friedman,

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Windows also admit solar radiation that heats building in cold seasons (ASHRAE. 2005). However. solar radiation and heat admission during cooling seasons poses a serious challenge since they increase cooling loads and need to be controlled. Also windows can work as a noise barrier. insulator. and as a protector from the glare if appropriately specified. The extensive functions of the window are summarized in Table 3.1.

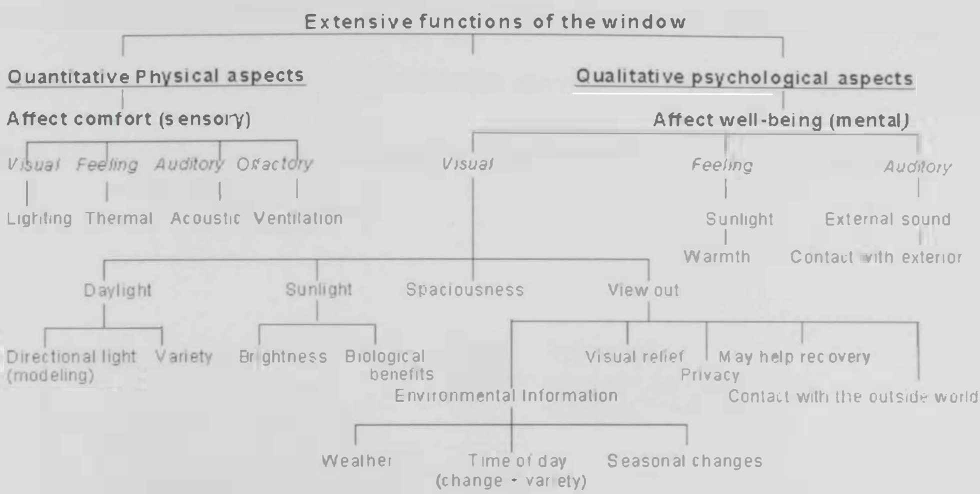


Figure 3.1: Extensive Function of the Window (Tabet Aoul, 2012)

As stated earlier the multiple functions of the window poses a serious challenge to the design process because of the conflicting roles assigned to windows. Consequently. setting priorities are necessary for the designer to meet the design objectives.

Given the contextual extreme hot climate of this research is rationale to set thermal control as the main target of this research. Hence. in this research. we are limiting ourselves to the thermal performance of the window in extreme hot climate. Therefore. heat gain reduction through window will be our focus.

3.3. Windows, Solar Radiation and Heat Transfer

Prior to establishing an approach for window designing for solar control. understanding of solar radiation and its behavior through the window is needed.

3.3.1. Solar Radiation

With a surface temperature of up to $6000C^0$. the sun produces a radiant spectrum with wave lengths extending from 20-3000nm. This radiant spectrum consists of Ultra violet. the visible radiation. and the infrared radiation (IR) (Szokolay. 2008). About 60% of the radiation is reflected by the atmosphere and only 9.5% of the radiation is absorbed by the earth and the air mass (Liébard and Herde . 2008). Figure 3.2 presents the distribution of the solar radiation received on earth:

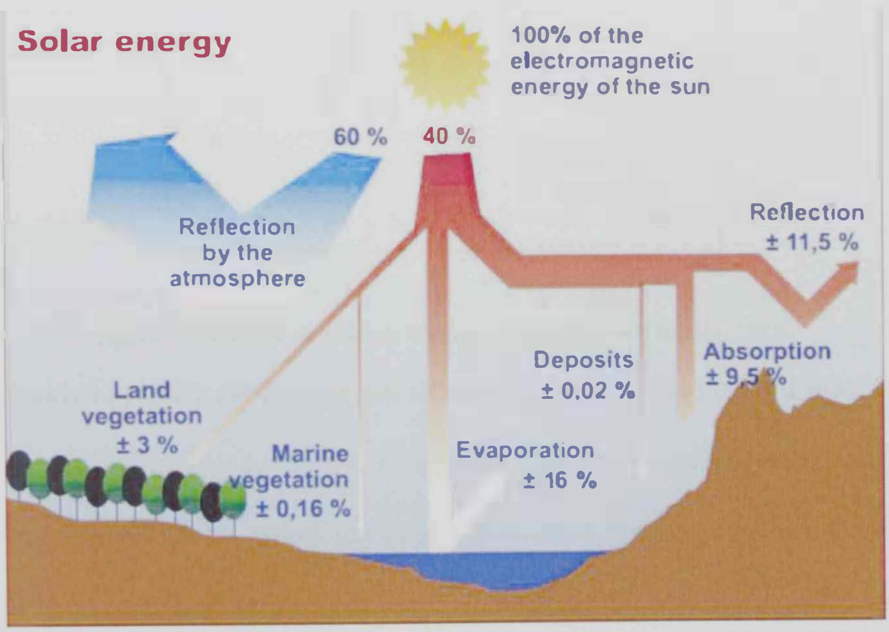


Figure 3.2: Distribution of Solar Radiation Received from the Sun (Liébard and Herde, 2008).

3.3.2. Heat Transfer

Selecting a highly performing window requires not only understanding of the heat flow mechanism through the window, but also understanding the heat transfer behavior through different type of glass. This crucial knowledge will enable the designer to determine his design approach to mitigate or eliminate heat flow.

There are three forms of heat transfer through a given medium; conduction, convection and radiation. These three forms of heat transfer are interacting together with complexity that makes separating them very difficult.

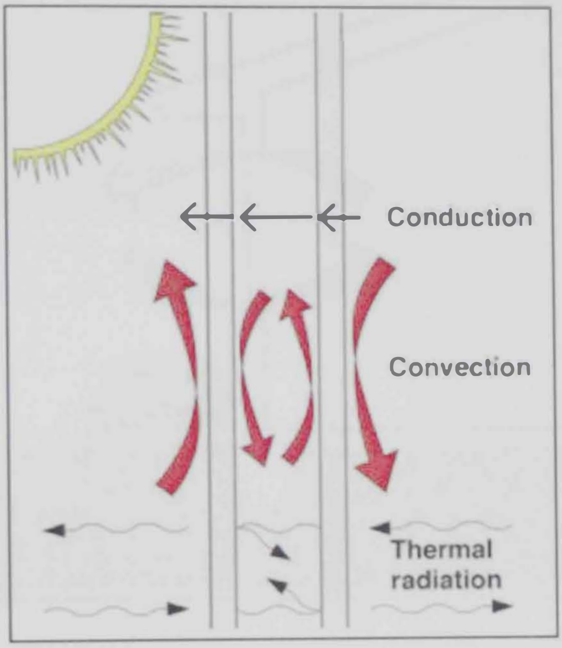


Figure 3.3: Heat Flow through Windows (Cardomy & Haglund, 2012).

Heat conduction is the movement and transfer of heat through a solid material like the glass and frame (Lyons, 2001). This heat travel can be mitigated by using poor heat conductors such as wood or vinyl for window frames, and insulated glass units.

Heat flow by convection is the travel of heat from a solid medium to a liquid or gas. Convection is affected by the difference of temperature between the two mediums and the contact area between them (Szokolay, 2008). However, radiation is the travel of heat through space. Szokolay, 2008 defines it as "*Radiation from a body with a warmer surface to another which is cooler*".

Moreover, Heat also may be transferred by air infiltration or leakage due to inappropriate window installation and cracks (Caromdy & Haglund, 2012).

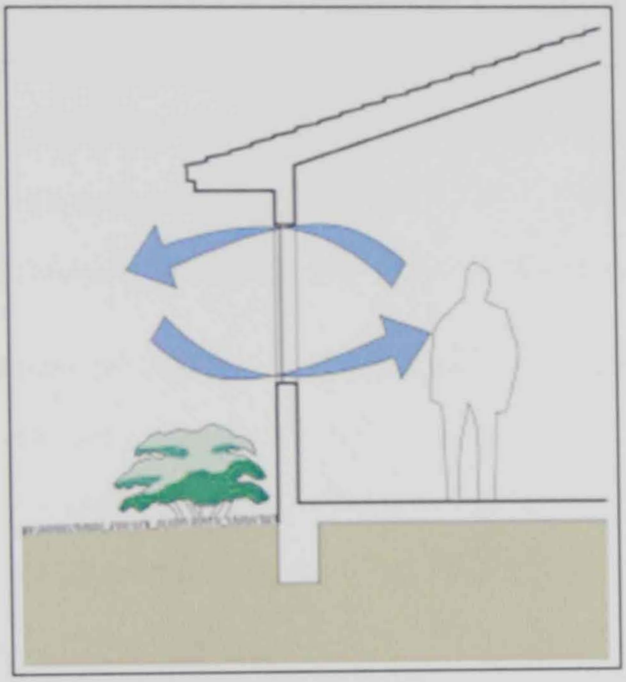


Figure 3.4: Air Infiltration in Windows (Cardomy& Haglund, 2012).

3.3.3. Window Thermal Characteristics

Window thermal behavior is being defined using a set of indicators are referred to as thermal characteristics. Window thermal characteristics are measured as follows: Heat transmittance is measured using U Value. Direct solar heat gain is measured using the Solar Heat Gain Coefficient (SHGC). The resistance to heat transmittance is measured by R Value. Finally, the visibility through window is measured by the Visible Transmittance (VT).

The first thermal characteristics indicator is the U Value, which is used to measure the heat transmittance through the window. The US Department of Energy, 1997, defines U Value As "*a measure of the rate of non-solar heat flow through a window or a skylight*". Clair, 2009, defines it as "*A measure that indicates how an element conducts heat*". While the R Value represents the resistance of a window or a skylight to heat flow through it and it is mathematically the reciprocal of the U Value (US Department of Energy, 1997). The U Value of a window is calculated as an average for both frame and glass and is measured using watts per square meter per Kelvin of temperature difference (W/m2.K) (Lyons, 2001). In the United States, U Value is measured using Btu/h·ft2·°F (Carmody & Haglund, 2012).

Heat gain is obtained from the direct and indirect solar radiation regardless of the differences in temperature. The solar heat gain is measured using Solar Heat Gain Coefficient (SHGC) which is defined as the rate of heat flows through a window or a skylight (by US department of energy, 1997). The SHGC is expressed in a dimensionless scale of 0 -1. The zero indicates that no solar radiation enters the window while one indicates an admission of 100% (Cardomym& Haglund, 2012).

Despite being an optical property, visual transmittance is an important performance indictor that is impacted by the characteristics of the glass. It shows the initial window function of providing daylight and view. Visible transmittance refers to the visible component of solar radiation which enters the window and is referred by VT (Stack et al, 2002).

3.4. Window Components

An adequate selection of a thermally performing window requires understanding of the thermal behavior of its influential components. Windows consist primarily of a frame and glazing. Shading device and insect screen are sometimes added if needed. In this section the two main components glass and frames are presented in terms of their physical and deriving thermal proprieties.

3.4.1. Glass

Glass is the most common glazing material used for windows, curtain walls and partitions. The history of glass manufacturing goes back to more than 4000 BC. Glass is an amorphous material composed of dolomite, boric acid, borax, field spathic materials, lead and barium compounds including the basic raw materials (Rathi, 2012).

Traditionally, glass has been manufactured using crown or cylinder methods, which limit the size and quality of the produced glass sheet. However, in the 1950's, the float glass method was introduced by Pilkington (Allen and Iano. 2009). This method guarantees a higher quality of produced glass in terms of surface finish and optical properties along with larger size of glass since manufacturing is now conducted in a controlled environment (Allen et.al. 2009).

Traditional clear glass, when used in windows, admits almost the majority of solar spectrum including ultra-violet (UV), visible light, and infra-red (IR). For instance the three millimeters clear glass admits 86% of radiant solar energy received by its surface. Hence, glass in its basic form is thermally inefficient and considered as a weak link between the outdoor and the indoor. For this reason, extensive studies were conducted to improve glass thermal performance. Often though, the enhancement of the thermal performance was achieved at the expense of daylight admission (Smith, 2005).

Glass with improved thermal properties, started to gain importance during the 1970's and 80's along with the growing awareness of the need for energy saving. Glass thermal performance improvements included various strategies that aimed to reduce heat gain through windows. Glass tinting, glass coating, and multi- layer glass are the common improvement strategies. Very recently, new glass technologies (called smart glass) were presented, but still in the research and development phase and still experience technical problems and high production costs that lead to limited usage.

a) Tinted and Coated Glass

The improvement in glass thermal performance targets the mitigation or elimination of heat flow through glass. Tinted glass aims at reducing the directly transmitted heat. Tinting is achieved by adding metal oxide to the produced glass during manufacturing. It is important to note that reflective glass eliminates heat gain by reflecting back solar radiation that strikes the glass surface but lowers the level of admitted light at varying levels based on the degree of glass tinting. Reflective glass is obtained by adding a reflective layer to glass pane. Low E glass (or low emissivity glass) is obtained by adding a low E coating which is generally a metal or metal oxide applied either during manufacturing or after manufacturing of the glass sheets. The low E glass provides the possibility to reduce heat gain through glass while maintaining satisfactory levels of view and daylight.

b) Multi-Layered Glass

The multi-layer glass or Insulated Glass Unit (IGU) is made by assembling two or more glass panes with an air or gas-filled space in between (ASHRAE, 2005). The air or gas space reduces heat conduction towards the indoors. Krypton or argon gases can be used instead of air as they are heavier gases and show higher resistance to heat conduction and convection (Harvey, 2006). The thermal performance can be further by having one of the glass panes tinted, reflective coated, or low E coated. This will guarantee the integration of their thermal properties and IGU insulating properties and ensures enhanced thermal performance.

Evacuated or vacuums- sealed glass can also reduce conduction and conviction through glass (Freidman, 2012). However, it does not resist radiative heat, so low E coting is required along with evacuation. Moreover, there is a structural problem with evacuated glass since it does not show enough resistance to wind force if applied on a large surface (Cardomy et al, 2004).

c) Smart Glass

In a more advanced form, smart glass, also referred to as Magic glass or switchable glass is a sophisticated combination of glass that can adapt its properties to the surroundings such as electrochromic glass (Figure 3.5), aerogels, and vacuumed glass. These types are still expensive and are not yet widely used. Although, they promise high performance in terms of thermal efficiency and introduce a great future thermal efficiency potential (Cardomy et al , 2004).

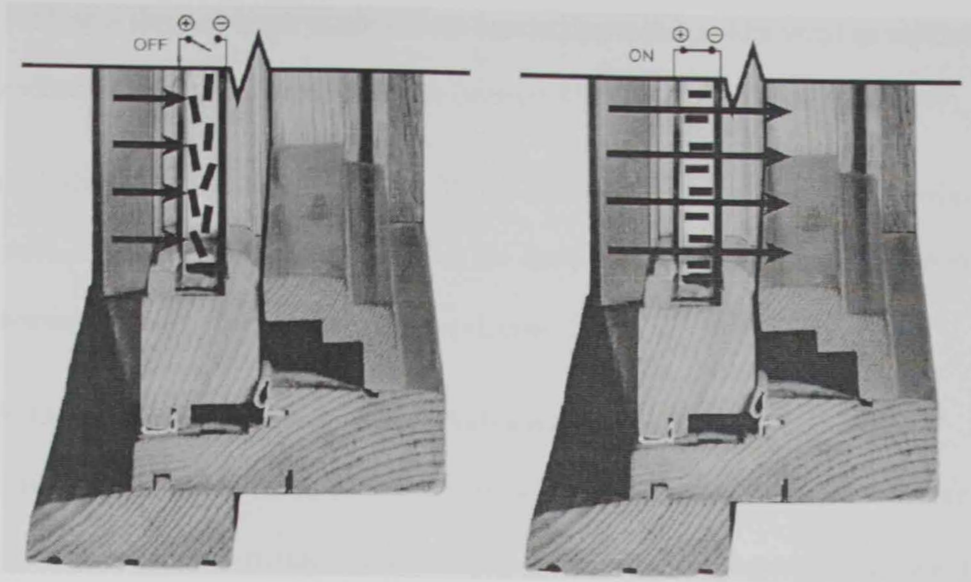


Figure 3.5: Electrochromic Glass Functioning (Friedman, 2012)

3.4.2. Frame

The second main component of a typical window is the frame. Frames can be made of several materials. Aluminum, wood, UPVC (Vinyl), and fiberglass are commonly used to manufacture window frames.

Wood is a high-performing frame material in terms of thermal efficiency since it is a poor heat conductor. However, wooden frames are not durable as other material and require regular maintenance (Lyons, 2001). Cladding the wooden frame with aluminum can solve the problem of poor durability and reduces the need for constant maintenance, but adds cost.

Aluminum stands as the most popular framing because of its strength, durability, and ability to be manufactured in complex section. It has become the most popular framing material since the Second World War (Lyons, 2001). However, aluminum conducts heat hundred times more than glass and affects the overall window thermal performance. Aluminum frame thermal performance can be improved by providing a thermal break made of non-conductive material like vinyl to separate the external face of the frame from the internal (US Department of Energy, 1997).

Un-plasticized polyvinyl chloride (UPVC), which is commonly known as vinyl frames, has good thermal properties that are comparable to wooden frames with the advantage of not requiring maintenance (Lyons, 2001).

3.5. Optimizing Windows Thermal Performance

Designing a window that responds to climatic conditions relies on several factors. Orientation, size, materials, and shading strategies are important factors in designing a thermally efficient window. Further, appropriate installation and regular maintenance are equally important aspects to maintain the specified performance.

3.5.1. Window Location and Orientation

Appropriate use of window orientation will contribute significantly in reducing building cooling loads through minimizing penetration and absorption of solar radiation (Clair, 2009).

In the UAE, the latitude and the high intensity of solar radiation on the east and west facades leave the northern orientation as the best location of opening make the best allocation and glazing (Clair, 2009). As per CIBSE, 1999, the preferred building orientation, the longest building axis is to be laid along the east-west axis with appropriate shading strategy at the south façade.

By comparison to other orientations, the north façade receives a smaller amount of solar radiation. For the south façade, the sun is in high position in the sky during the overheated period, so the undesired solar radiation could be eliminated using proper shading strategy (CIBSE, 1999).

3.5.2. Window Size

Window size is one of the important parameters that influence window thermal and daylight performance. However, heat gain and daylight are in conflict, which means that the larger window can provide desired daylight but, could also allow undesired heat gain (CIBSE, 1999).

According to Fathy (1986), reducing the area of windows and locating them at only two of the building façades will provide a 55% saving in the energy use. Aboulnaga et al. (2000) recommends keeping glazing area at about 10-20% of the overall façade area for better thermal performance.

3.5.3. Material Selection for Solar Control

The appropriate window material selection can significantly contribute in reducing heat gain through windows. Hence, designers should focus on selecting materials that reduce all forms of heat transfer. Deciding the number of glass panes, the type of coating, and the frame material will determine the window thermal efficiency (Cardomy& Haglund, 2012).

Since clear uncoated glass allows almost 80% of solar heat gain, other glass options can provide greater improvement. For example glass with high reflective coating can reduce the heat gain by 20% (Cardomy & Haglund, 2012).

Reducing heat transfer through window depends on the material of both main components of the window frame and glass.

Consequently, a material with lower heat transmittance (i.e. Low U value) should be selected for a window assembly. As stated in the previous section, aluminum frames are the most popular framing material. However it is not the most appropriate selection in terms of heat conductance since it is a very good heat conductor. Wooden frames, vinyl frames or aluminum frames with thermal break have better performances in terms of heat transmittance and lower in U value and are preferable in optimizing thermal performance (Allen and Iano, 2009). Table 3.1 shows the different types of frames with its U value.

Table 3.1: Different Types of Frames and Overall Window U Factor (Allen and Iano, 2009)

	Overall U-Factor[a]		
Window Frame	Single-Glazed	Double-Glazed, Clear	Double-Glazed, Low-e, Argon Gas
Aluminum, without thermal break	1.2 *6.8*	0.76 *4.3*	0.60 *3.4*
Thermal break aluminum	1.0 *5.7*	0.63 *3.6*	0.48 *2.7*
Steel	0.92 *5.2*	0.55 *3.1*	0.41 *32.3*
Wood, clad wood, vinyl	0.84 *4.8*	0.49 *2.8*	0.35 *2.0*
GFRP	0.65 *3.7*	0.44 *2.5*	0.27 *1.5*

[a]U-factor: Btu/ft^2-hr-°F followed by W/m^2-°K

Glass material selection, which is the main window component, is of a great importance in terms of thermal performance. The selected glass material should offer resistance to all possible heat flows such as direct solar radiation and heat transmittance. Tinted glass and reflective glass can offer reduction in direct solar gain. However they do not offer resistance to heat transmittance when it is in the form of a single pane. Another disadvantage of the reflective and highly tinted glass is that it has a low visual transmittance and does not allow the admittance of adequate daylight.

Doubling the tinted or reflective glass to be within an insulated glass unit with air or gas gap improves its thermal performance in terms of heat transmittance. Triple pane glazing offers an improved resistance to heat transmittance but, if compared to improvement obtained by doubling the single pane, is not significant (Friedman, 2012). Table 3.1 and figure 3.4 show the reductions obtained in glass U value by using more than one glass pane:

Table 3.2: Glazing Types with their U values. (Source: Smith, 2005)

Glazing	U-value (W/m^{2}K)
Single glazing	5.6
Double glazing	3.0
Triple glazing	2.4
Double with Low E	2.4
Double with Low E and Argon	2.2
Triple with 2 Low E and 2 Argon	1.0
Double with Aerogel	0.5–1.0

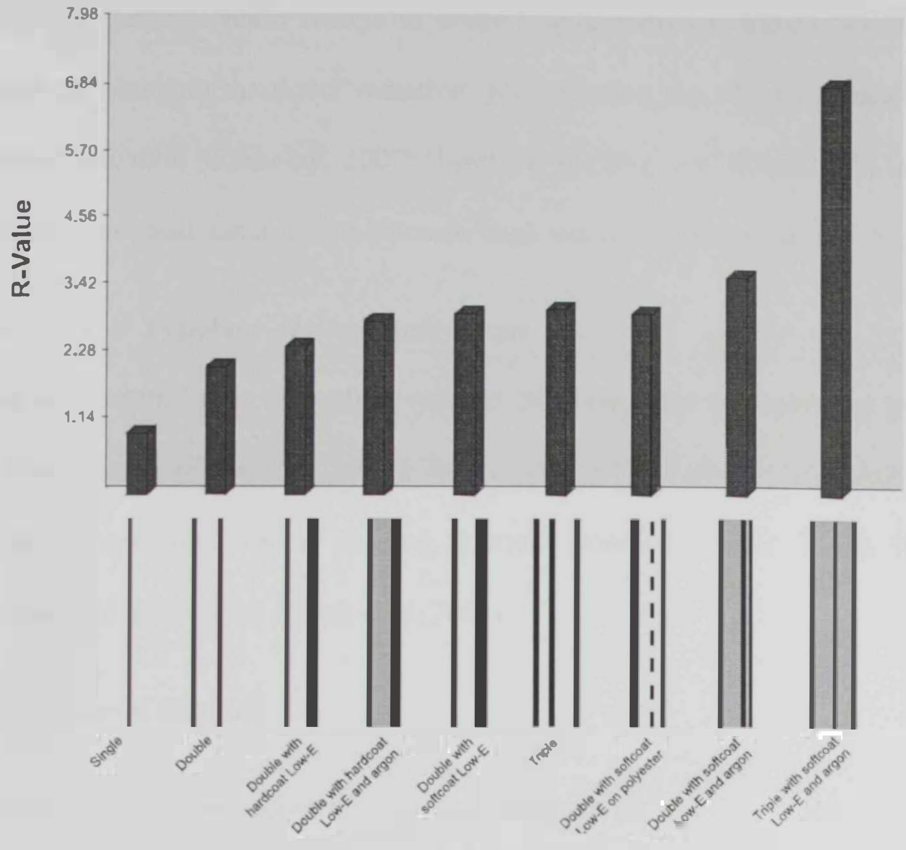


Figure 3.6: Resistance of Different Glass Units to Heat Transmittance (Friedman, 2012)

The low emittance glass or Low E glass provides a better opportunity in terms of thermal performance and daylight admittance. The low E coating is commonly used within insulates glass units and reduces the radiative heat between the glass panes and the heat transmittance of the whole glass unit (Allen and Iano. 2009). Table 3.2 indicated that the low E coated double glass unit exceeds the triple glazing in terms of resistance to heat transmittance.

3.5.4. Window Shading for Solar Control

Shading windows in hot climates provides an opportunity for significantly reducing windows solar heat gain. Since it is designed according to the seasonal sun path. it offers the best performance in the overheated period (Olgyay. 1963).

3.5.4.1. The Role of Shading:

A shading device's main role is to control solar radiation hitting the building surface by blocking the direct radiation, and reducing the effect of diffused and reflected radiation (Szokolay, 2007).However, shading can influence the level of daylight, view, and natural ventilation through window (Stack et al, 2002).

3.5.4.2. Typology of Shading Systems

There are several forms of shading systems. Shading could be internal or external, fixed or movable (Stack et al, 2002). The selection of a shading system depends on several factors: function of shading, climatic conditions, site layout, type of building, and orientation. (Stack et al, 2002).

a. Natural Shading

Shading obtained from adjacent trees and vines can provide a suitable solution for solar radiation at certain orientations during the overheated period (Stack et al, 2002). A strategic planting of deciduous and evergreen trees on the east, west, south east, and south west can provide the required shading (Olgyay, 1963). Givoni, 1994, stated that trees could contribute in reducing cooling loads of a building through blocking radiation without obstructing ventilation. It can also reduce wind speed near the exterior walls. Additionally; grass and vegetation around buildings can reduce reflected radiation.

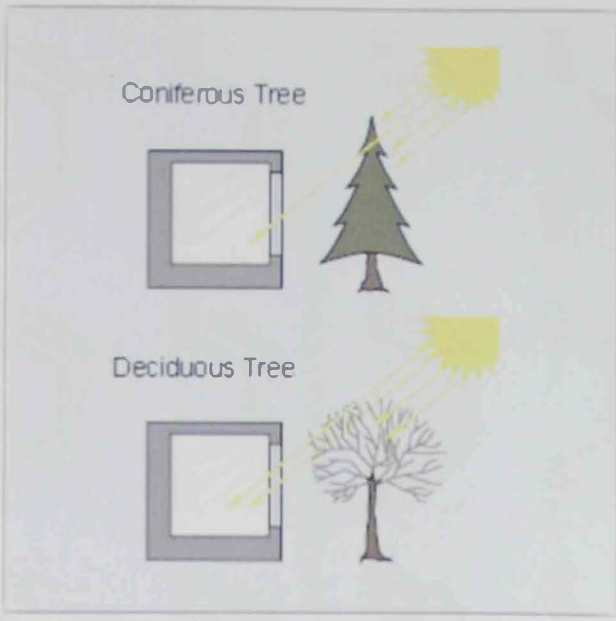


Figure 3.7: Trees as Natural Shading Device (Stack et al, 2002).

b. External Shading Device

The external shading device provides the best protection from solar radiation (Stack et al, 2002). With the use of an external device, the protection efficiency will increase by 35% more than internal shading (Olgyay, 1963). External shading devices could be fixed in form of horizontal overhangs, vertical fins, a combination of horizontal and vertical fins which are called egg-crates, and permanent awnings and shutters.

Fixed devices are simple and have a low maintenance cost. They provide an opportunity to be used as an architectural element (Stack et al, 2002).

One more option for external devices is the movable device, in form of movable louvers, or blinds. The movable device could be manually controlled or automated. This movable shading provides adaptability to the sun motion and provides maximum opportunity to provide the required day light and view while blocking undesired heat (Stack et al, 2002).

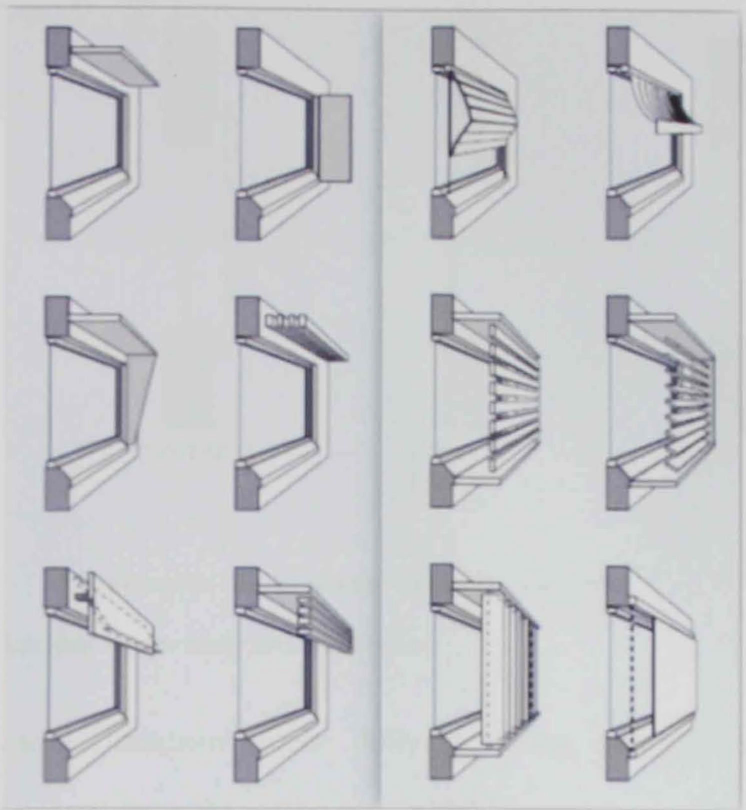


Figure 3.8: External Shading Devices (Stack et al, 2002).

c. Interior Shading

An interior shading device comes often in the form of curtains, Venetian blinds, or roller shades (Stack et al, 2002). The interior shading device intercepts the radiation which just passed through the glazing and can only eliminate the radiant portion of radiation by reflecting back through radiation, while some of energy will be absorbed, and reradiated into the room (Olgyay, 1963). This is the reason why the interior shading device is not thermally efficient during the overheated periods (Stack et al, 2002).

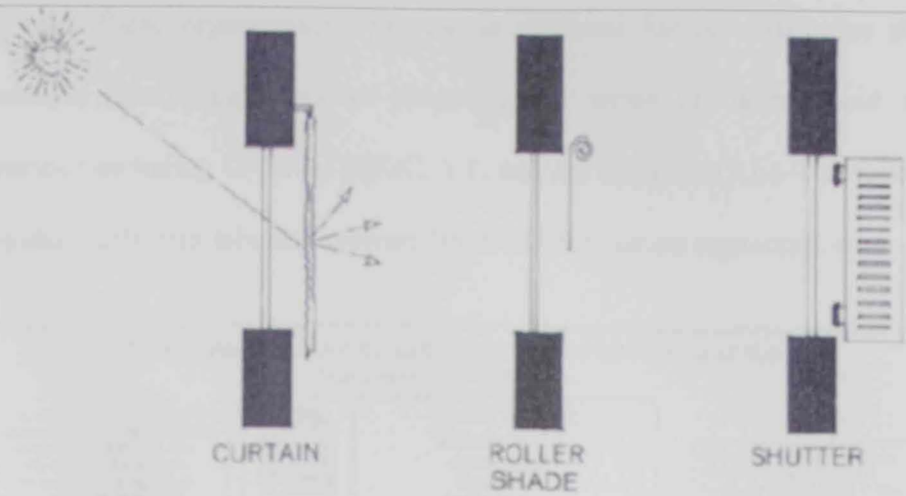


Figure 3.9: Interior Shading Devices (Lechner, 2009)

Optimum Shading According to Orientation

Different façade orientations require different shading strategies. For façades oriented to the south where the sun latitude is high at overheated period, horizontal overhangs would be appropriate to eliminate undesired radiation (Stack et al, 2002). For east and west oriented façades vertical fins could give protection to some extent, but it blocks the daylight as well. Movable shading device and well planned vegetation could provide better protection for the low angled solar radiation (Stack et al, 2002).

3.6. Windows Rating

The need of having window rating agencies became a necessity in light of the large number of products available in the market, and the growing energy saving trends. Window rating provides designers, customers, and contractors with the required thermal and visual performance data to meet their window design specifications.

There are several international rating organizations such as National Fenestration Rating Council (NFRC) in the United States, the Australian Fenestration Rating Council (AFRC) in Australia, and the British Fenestration Rating Council (BFRC) in the UK. These organizations provide in different formats otherwise similar information, identifying windows proprieties in terms of thermal and visual performance including U value, SHGC, VT, and Air Leakage (AL). The following figures show different labeling systems from different rating organizations.

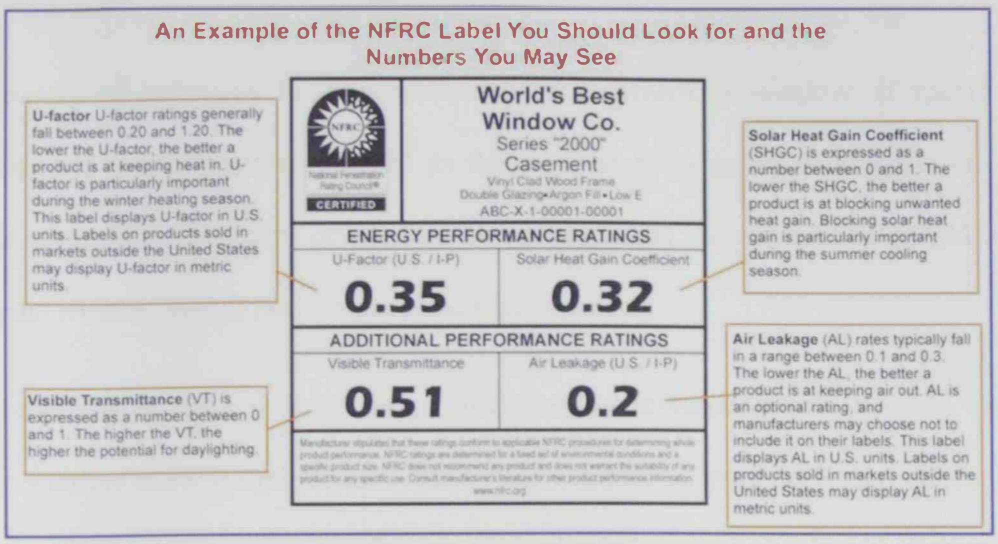


Figure 3.10: National Fenestration Rating Council (NFRC) Window Label (NFRC, 2013)

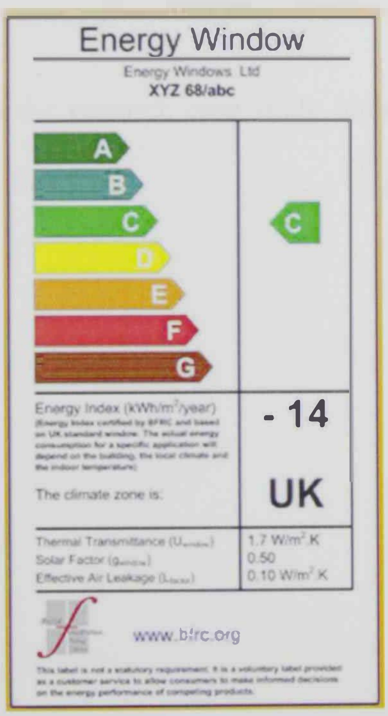


Figure 3.11: British Fenestration Rating Council (BFRC) Window Label (BFRC, 2013)

3.7. Conclusion

Designing a window with high thermal performance requires both a detailed understanding of the heat transfer mechanism through window and a good knowledge of possible sun control strategies including locating, sizing, material selection and shading of windows.

Because of extensive field research and development, a window, if specified properly, is no longer considered as the weakest point in the building envelop. However, other functions of window like daylight and view should be considered in the window design performance and maintenance.

The review of window solar design strategies has revealed several possible ways for window thermal optimization. However, window material selection was found to be the design strategy that fits the thermal window optimization in relation to variable orientation and meets the research main objective. The material selection included the selection of efficient glass and frame material.

The next chapter presents the research case study including the current window design, treatment and specifications.

4. CHPTER FOUR: CASE STUDY: AL FALAH COMMUNITY IN ABU DHABI

4.1. Al Falah Community; Overview

Al Falah community project was selected as the case study for this research. It is one of the recently launched Emirati Family Housing Programs in the Emirate of Abu Dhabi as part of the famed Abu Dhabi 2030 Vision. The program aims at providing multi-option housing for local families while accommodating cultural and sustainability values through design and construction (UPC, 2011).

Al Falah is a master plan community designed to provide all community facilities besides offering alternative housing options for the Emirati citizens. The community consists of a town center and five residential villages with about five thousand residential detached houses coming in nine different designs varying in terms of size and architectural style (G.H.M. Nov.2009). The town center in Al Falah includes hotels. town houses and apartments. retails. shopping mall. a hospital and sport facilities (UPC. 2011).

Three phases of Al Falah community were completed and handed to citizens by August. 2013. Each phase included about 1000 villa.

Figure 4.1: Arial View of Completed Phases of Al Falah (ALDAR, 2013)

4.2. Location of Al Falah Community

The community is located to the east of Abu Dhabi International Airport and Abu Dhabi- Dubai highway and to the north-east of the city of Abu Dhabi (Figure 4.1). It occupies an irrigated desert land with an area of 13.5 km2 (G.H.M, Nov.2009). Al Falah also is surrounded by four existing roads (Figures 4.2, 4.3).

Figure 4.2: Al Falah Location in United Arab Emirates (Source: Google Maps, 2013)

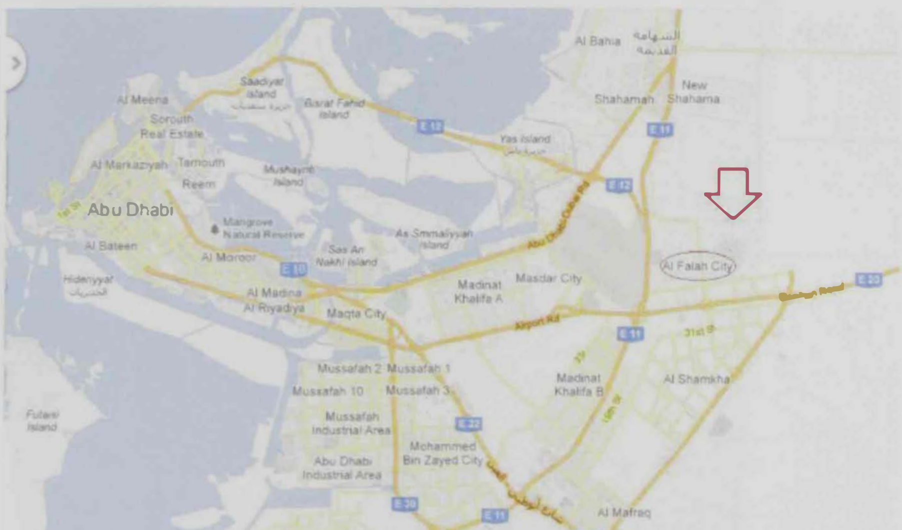


Figure 4.3: Al Falah Location in Abu Dhabi City (Source: Google Maps, 2013)

4.3. Al Falah Planning and Zoning

The master plan is a hexagon bound by four existing roads. According to G.H.M. the designer, the selection of hexagonal as a defining shape was borrowed from the vibrant tradition of using geometric principles in the Islamic architecture and art (G.H.M. Nov.2009).

Al Falah master plan is divided into six almost equal triangles. Five of them include the five residential villages while the sixth will house the town center.

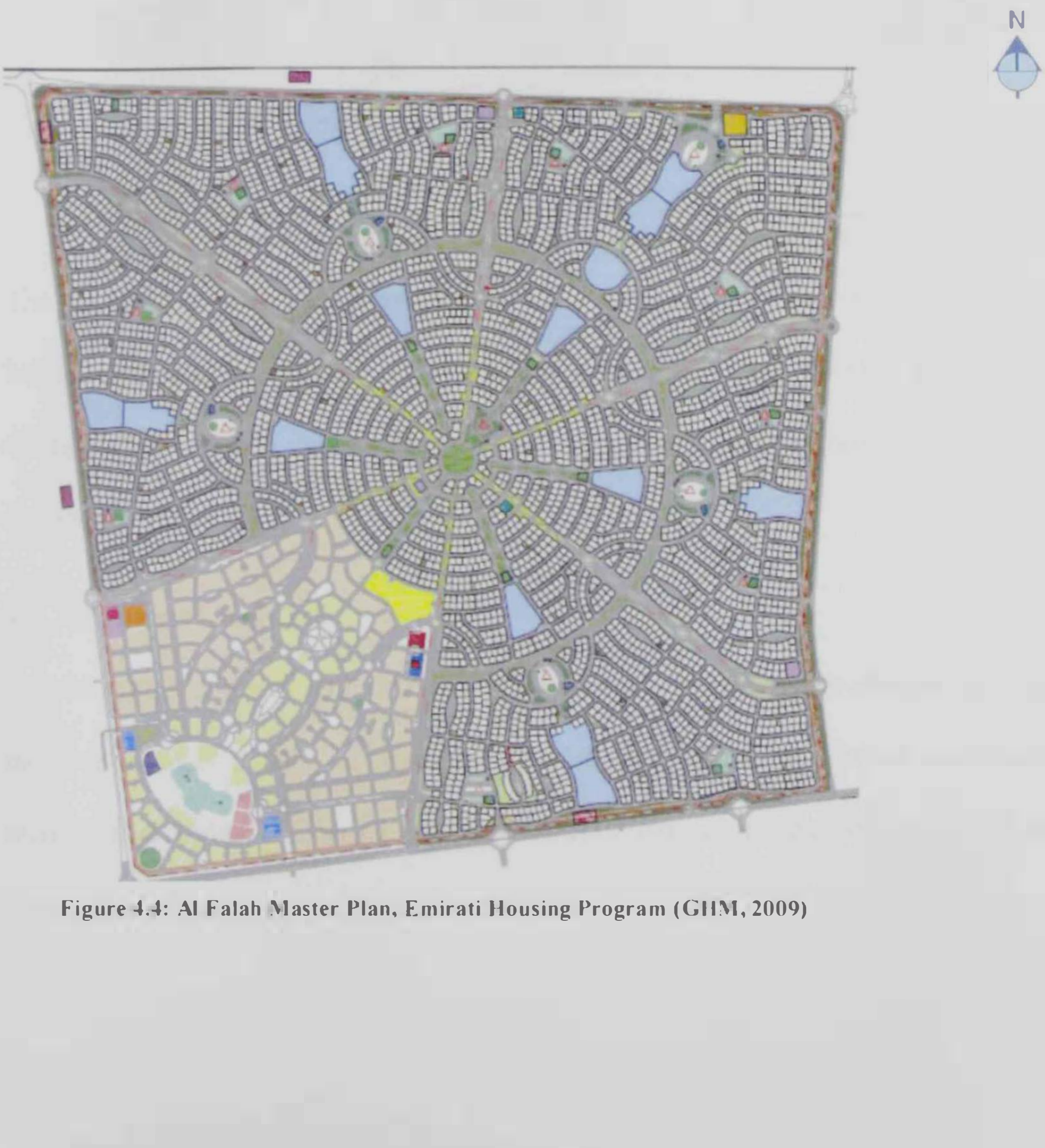


Figure 4.4: Al Falah Master Plan, Emirati Housing Program (GHM, 2009)

Figure 4.5: Al Falah Planning Concept (GHM, Nov.2009)

The planning geometry is aligned towards the south west where the town center is located in order to enhance center primacy (G.H.M, Nov. 2009). Houses in villages are located to face roads. Gardens are located in front of houses to provide defensible spaces.

4.4. Housing at Al Falah

Five of the six zones at Al Falah community are residential neighborhoods. In total the five villages consist of around 4800 detached houses in various sizes and architectural styles. Table 4.1 indicates houses distribution per village which is over 1000 units in four out of the five villages.

Table 4.1: Al Falah Houses Distribution per Village

Village	1	2	3	4	5
No. of villas	1036	1012	1010	730	1044

Houses in each village are being served by a number of retail shops, clinics, coffee shops, and salons located at the center of each village. Several shops are allocated within neighborhoods to serve residents (G.H.M. Nov.2009).

4.4.1. Classifying Al Falah Houses: Typology

For this research, Al Falah design and planning documents were surveyed in order to classify houses in terms of size; architectural style and type of construction with an interested focus on building envelop construction material. This survey aimed at finding out prevailing house sizes, architectural styles and construction material characteristics.

The survey revealed that houses at Al Falah villages have been intentionally designed in different sizes and architectural styles. This diversity in design was intended as one of the objectives of the master Plan aiming to provide multiple choices for local families to meet different family sizes and personal preferences. Villas are located in plots with the size 30 mX35 m, and surrounded by 2.5 m height boundary wall (G.H.M, Nov.2008).

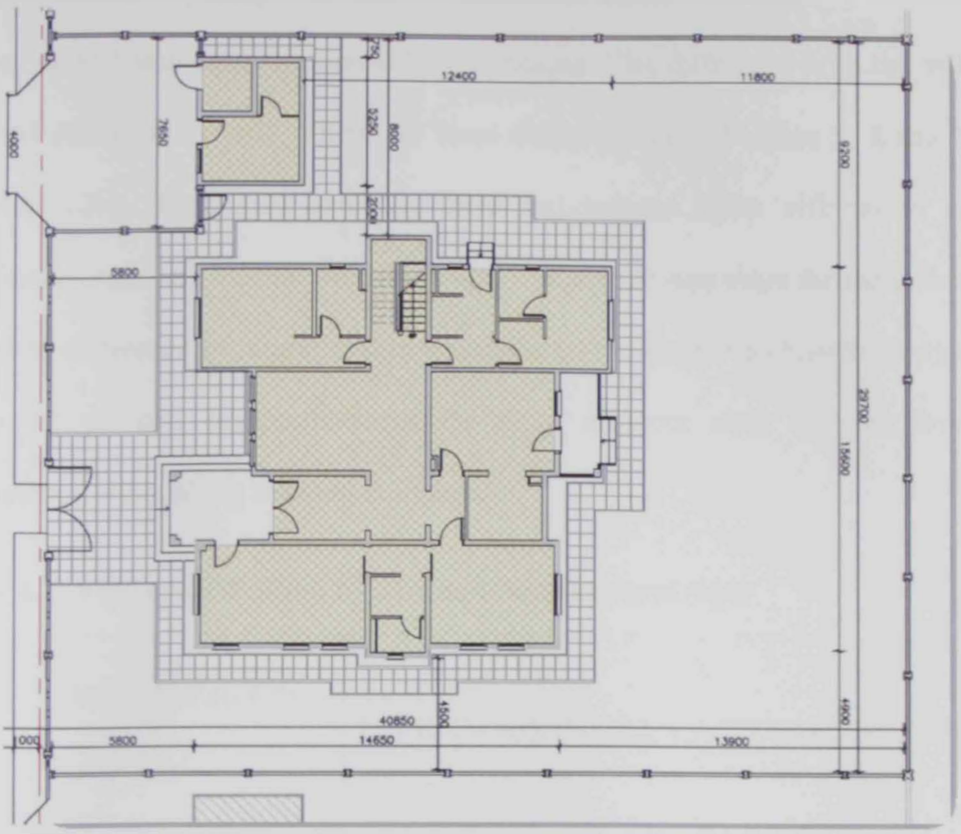


Figure 4.6: Sample of a Villa Plot (GHM, Nov2009)

Figure 4.7: Five-bedroom Villa Footprint within the Plot

4.4.2. Housing Typology, Size and Architectural Styles

Houses at Al Falah come in nine different designs. The difference is in the villa size and architectural style. There are three different sizes of villas; 3, 4 and 5-bedroom villas. Each villa size has three architectural styles referred to as; Andalucia, Gulf Heritage and Modern. Villas of the same size share the same floor plan with difference in façade design according to the desired architectural style. Table 4.2 presents perspectives for the three different sizes and the three architectural styles along the total built area.

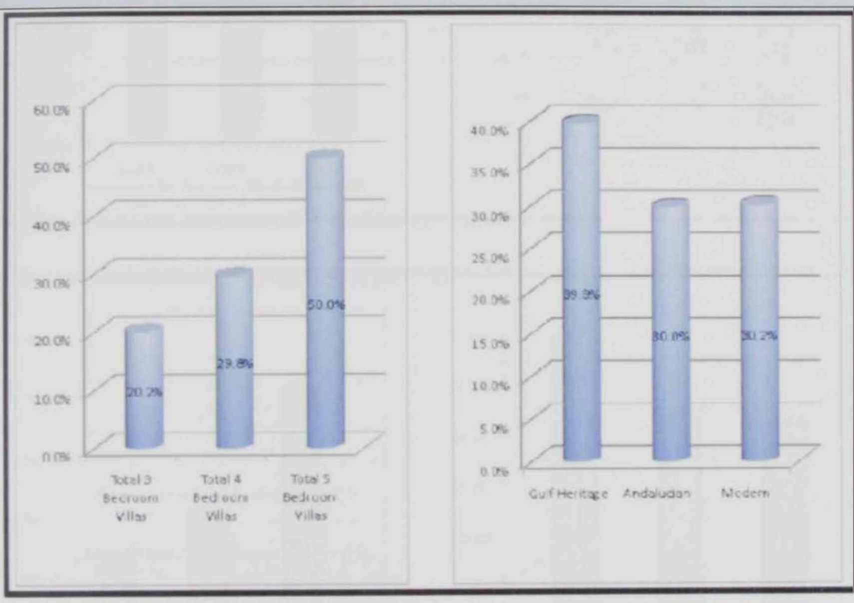
Table 4.2: Villa Classification by Size and Architectural Style

	THREE BEDROOM VILLA	FOUR BEDROOM VILLA	FIVE BEDROOM VILLA
ANDALUCIA			
GULF HERITAGE			
MODERN			

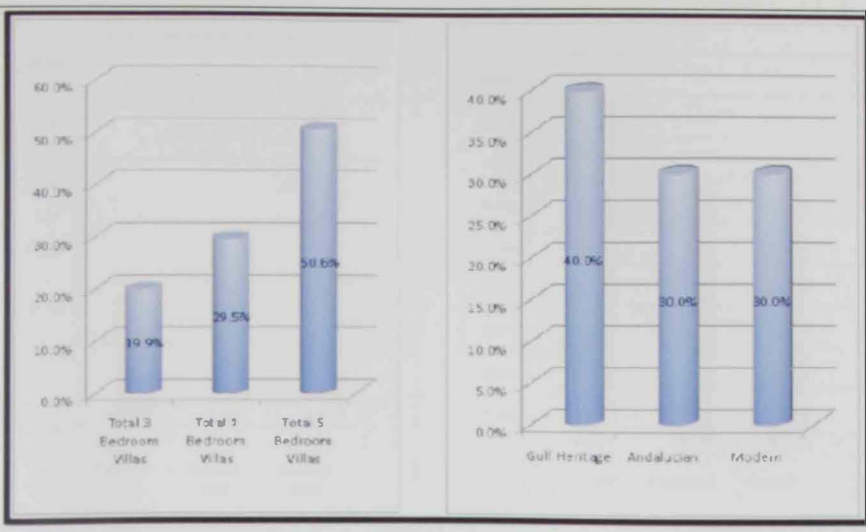
Number of stories	1Story	2 Stories	2Stories
Floor Area	293.15 m^2	356.96 m^2	418.38m^2

As shown in table 4.3, a design review reveals that the five bedroom villa is the dominant size in all five villages and accounts for almost 50% of the total number of houses. On the other hand, Gulf Heritage style largely appeared as the dominant architectural style.

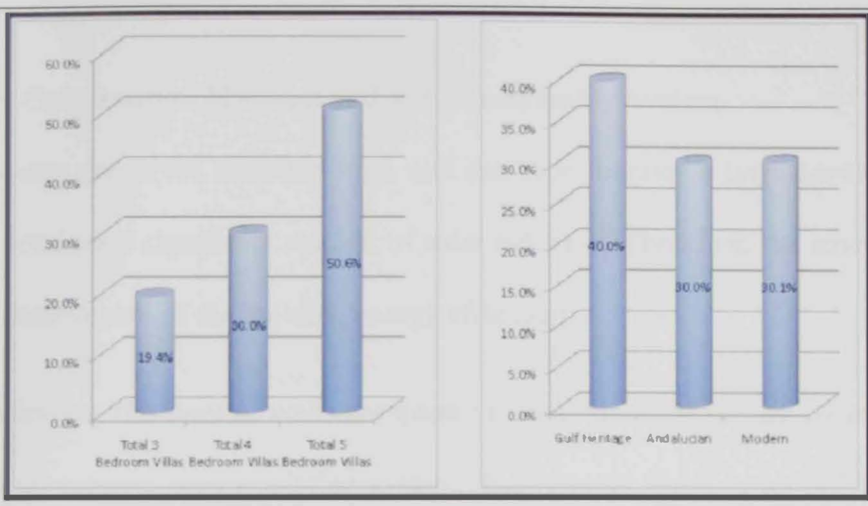
Table 4.3: Designers Review for Al Falah Houses Sizes and Styles (GHM, April 2009)

Village	Results of Distribution of houses per size and style in each village Review
Village 1	

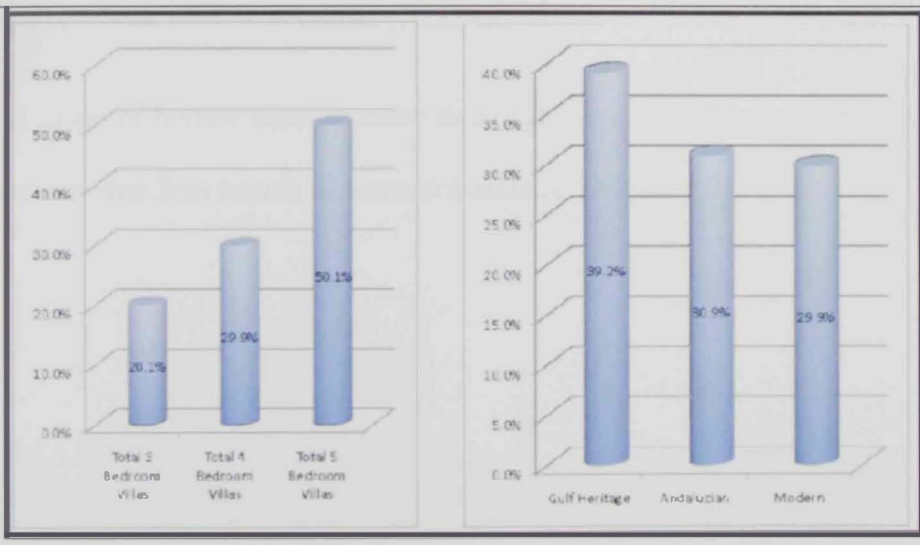
Village 2

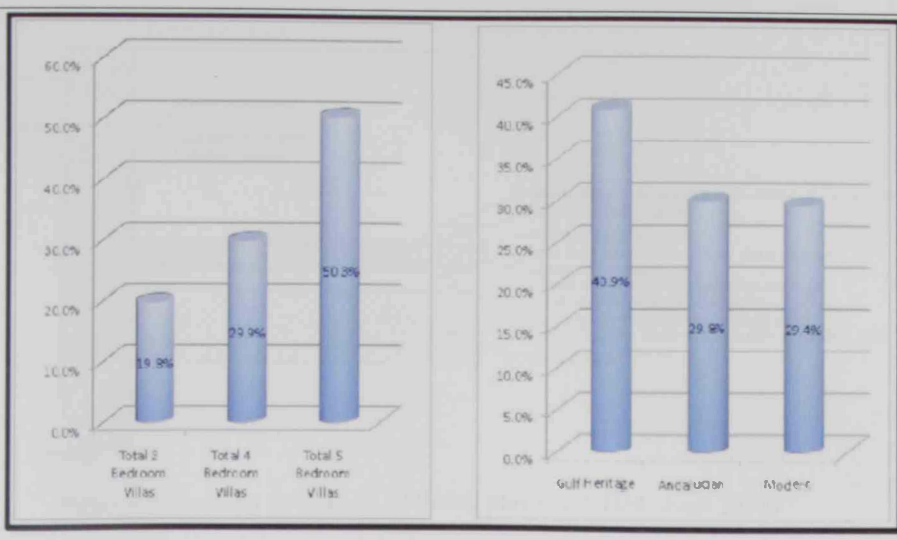


Village 3



Village 4



Village 5	

4.5. Houses Construction Material and Air Conditioning System

Al Falah houses are of the detached type, and this type features a large envelope area which receives a significant amount of solar radiation. Therefore, the envelop is a crucial determinant of the building energy efficiency.

In Al Falah houses, the exterior walls are made of 20cm insulated precast concrete panels with an exterior epoxy painting system. The internal finish is water-based emulsion and ceramic tiles in wet areas (ALDAR, 2009).

The roof is made of hollow core concrete slab, light weight foam concrete above and with polystyrene 5cm boards as thermal insulation (Figure 4.9).

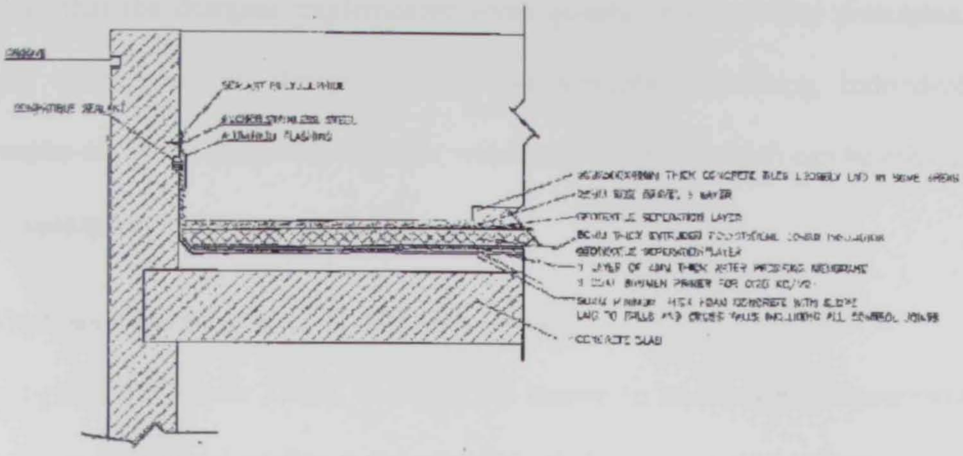


Figure 4.8: Roofing System in Al Falah Houses (GHM, June 2009)

Windows are made of aluminum conventional frames with double pane tinted low reflective glass.

The houses are cooled using package Air Conditioning units.

4.6. Sustainability Measures at Al Falah Houses

Prior to examining the thermal performance of the windows in Al Falah houses, the existing sustainability measures should be investigated.

At the time of design and commencement of construction Estidama, the local sustainability framework measures, were not implemented for low-rise housing. Therefore, designers have considered general sustainability principles in design.

This approach was used in Al Falah. GHM, the Al Falah designer, improved indoor environmental quality and achieved energy saving by both using better U values of the exterior envelop and specifying highly-performing HVAC systems. The design was verified against ASHRAE 90.2.

Efficient water fitting were also provided the achieve water saving at Al Falah houses (G.H.M, Nov 2009).

It is clear that the designer implemented some general sustainability principles. However there was no design effort done towards optimizing individual components of the building such as walls, windows, and roofs which can be critical in determining building energy efficiency.

4.7. Windows Characteristics in Al Falah Houses

As highlighted in Chapter Three, windows are known to be a crucial determinant of indoor environmental quality and optimized windows increase building energy efficiency. And since this research focuses on the optimization of window design, in this part, several parameters of window design need to be addressed then opportunities for optimization will be explored. Window design critical parameters are; window orientation, window wall ration (WWR), window material and shading and will be discussed below. The specified characteristics in Al Falah houses are reviewed next.

4.7.1. Window Orientation

Window orientation is a determining parameter that greatly impacts the window and the building overall thermal performance. Since different orientations receive different amounts of solar radiation, windows in extreme hot climates are supposed to be oriented and placed facing the directions that receive the least radiation (Al Temeemi, 1994). In Al Falah Master Plan, houses are located facing the main roads.

Figure 4.9: Partial View of AL Falah Showing Different Orientations

Yellow	South- west	Blue	North-east
Lilac	South-east	Red	North-west

Figure 4.10: **Partial View of Enlarged Capture from Al Falah Showing Different Orientations**

Yellow	West	Light pink	North-east
Red	South	Blue	South-east
Green	East		

Figures 4.10 and 4.11 clearly indicate that villas are located to face the main roads as per Town planning needs and requirements. All houses show the same type of windows regardless of the orientation. There are no window treatments to control heat as per orientation requirements. This decision is often governed by architectural unity needs. Hence, there was no attempt to adequately adapt the window design to the given orientation.

4.7.2. Window to Wall Ratio

Windows are considered the weakest elements in the building envelop. Therefore windows can be sized to mitigate the high solar radiation (Aboulnaga, 2000). Consequently, the window-wall ratio is important in determining the amount of heat gain for a particular building.

A survey of Window Wall Ratio (WWR) for the dominant 5-bedroom villa was conducted with the objective to investigate and find out the window wall ration for each individual interior livable space. The survey was done for the three types of the 5-bedrooms villas in order to ensure that the potential relevance and applicability of the study to all Tables 4.4, 4.5 and 4.6 show the results of the survey of spaces window wall ratio (WWR) and window floor ratio (WFR). The calculations of WWR & WFR were done for each individual space. The WWR for living rooms and bedrooms were found ranged from around 20% to about 50% of spaces exterior walls. The survey also indicates opportunities to optimize windows in such spaces.

Table 4.4: Window Wall Ratio for a 5- Bedroom Villa (Andalucía)

Space Name	Floor area M2	Wall area M2	Window area M2	WWR 100%	WFR 100%
GROUND FLOOR					
MAJLIS	26.6	30.885	10.12	32.7	38
LIVING	18.4	11.6	6.3	54.3	34.24
BEDROOM 1	18	11.6	3.52	30.34	19.55
MAID ROOM	9.8	11.6	2.08	17.93	21.22
COOKING	20	11.6	1.725	14.87	8.625
DINING	20	26.1	6.48	24.82	32.4
IRON ROOM	10	7.25	1.065	14.68	10.65
FIRST FLOOR					
BEDROOM 2	18	11.6	3.52	30.34	19.55
BEDROOM3	19.8	11.6	3.52	30.34	17.77
BEDROOM 4	18	11.6	2.6	22.41	14.44
M. BEDROOM	18.8	11.6	3.52	30.34	18.72
LIVING	16	11.6	3.6	31.03	22.2
THE HALL	10.4	7.54	1.9	25.2	18.27
STAIRCASE	12.54	9.97	3.4	34.1	27.11
TOTAL WINDOW AREA			53.35		

Table 4.5: Window Wall Ratio for a 5-Bedroom Villa (Gulf Heritage)

Space Name	Floor area M2	Wall area M2	Window area M2	WWR 100%	WFR 100%
GROUND FLOOR					
MAJLIS	26.6	30.885	10.12	32.76	38.04
LIVING	18.4	11.6	6.6	56.89	35.86
BEDROOM 1	18	11.6	2.08	17.93	11.55
MAID ROOM	9.8	11.6	2.08	17.93	21.22
COOKING	20	11.6	1.725	14.87	8.625
DINING	20	26.1	6.48	24.83	32.4
IRON ROOM	10	7.25	1.065	14.69	10.65
FIRST FLOOR					

BEDROOM 2	18	11.6	2.08	17.93	11.55
BEDROOM3	19.8	11.6	2.08	17.93	10.50
BEDROOM 4	18	11.6	2.6	22.41	14.44
M. BEDROOM	18.8	11.6	3.52	30.34	18.72
LIVING	16	11.6	3.9	33.62	24.37
THE HALL	10.4	7.54	3.36	44.56	32.30
STAIRCASE	12.54	9.97	3.4	34.10	27.11
TOTAL WINDOW AREA			51.09		

Table 4.6: Window Wall Ratio for a 5-Bedroom Villa (Modern)

Space Name	Floor area M^2	Wall area M^2	Window area M^2	WWR 100%	WFR 100%
GROUND FLOOR					
MAJLIS	26.6	30.885	10.08	32.64	37.9
LIVING	18.4	11.6	7.2	62.07	39.13
BEDROOM 1	18	11.6	2.88	24.83	16
MAID ROOM	9.8	11.6	2.88	24.83	29.4
COOKING	20	11.6	1.725	14.87	8.625
DINING	20	26.1	7.68	29.42	38.4
IRON ROOM	10	7.25	1.065	14.7	10.65
FIRST FLOOR					
BEDROOM 2	18	11.6	2.88	24.83	16
BEDROOM3	19.8	11.6	2.88	24.83	14.55
BEDROOM 4	18	11.6	3.6	31	20
M. BEDROOM	18.8	11.6	3.52	30.34	18.7
LIVING	16	11.6	5.4	46.55	33.75
THE HALL	10.4	7.54	2	26.53	19.23
STAIRCASE	12.54	9.97	5.44	54.6	43.4
TOTAL WINDOW AREA			59.23		

The window to wall ratio comparative analysis between the different styles enables to draw the following: First, the three architectural styles of the five-bedroom houses feature close ratios of glass areas. Second, the modern architectural type has the largest glazed area compared to the other two. Third, living rooms at the first and ground floors feature the largest WWR which may result in significant increase of heat gain into the space especially when facing east or west.

4.7.3. Window Materials

Window material is another component to be considered while optimizing window design. An appropriate material contributes in the reduction of heat gain through the window (Al Temeemi, 1994).A thorough review of the window materials as indicated in the project tender documents and details was conducted in order to find out possible weaknesses in the existing design that can be improved or optimized.

The review indicated that windows frames are made of powder coated aluminum profiles while glass is tinted low reflective double glass with 6mm thick glass panes with a 12mm air gap (Figure 4.11) (ALDAR, 2009).

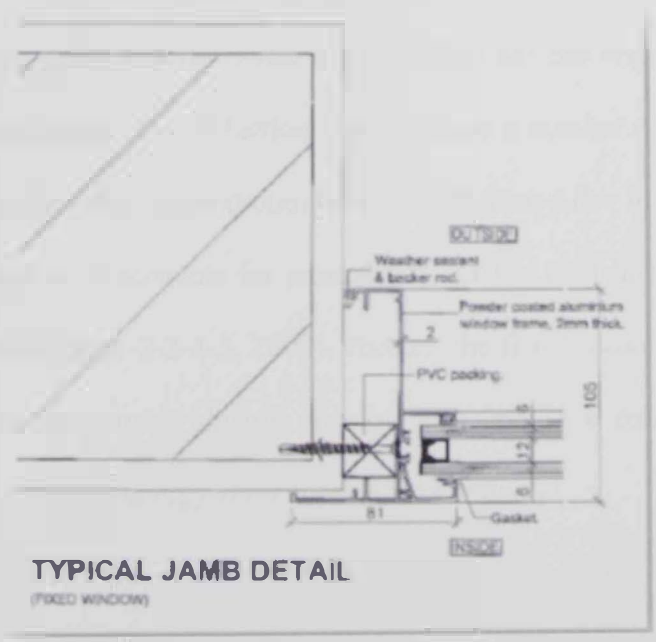


Figure 4.11: Window Jamb Detail (ALDAR, 2009).

4.7.4. Window Shading

As elaborated in Chapter Two, shading is of a great importance in extreme climate as it blocks solar radiation (Clair, 2009). However, our review of Al Falah plans indicates that no shading strategy was implemented, except one glazed door in the master bedroom at the first floor of the modern villa style (Figure 4.13).

Figure 4.12: Absence of window shading in all styles homes (Five Bedroom Villas)

Undoubtedly, the absence of shading in the existing design opens a great opportunity for the window optimization process.

4.8. Selection of the Villa for Investigation

The five bedroom modern style house was selected for the window's thermal performance optimization. This selection was based on a number of factors. First, in terms of house size; the five-bedroom house was selected due to its dominance in the development as it accounts for around 50% of the total houses within the community (G.H.M Parts1-2-3-4-5, 2009). Further, the five-bedroom villa had the largest floor area and largest glazing envelop area and as a consequence, has shown the highest rates of energy consumption for cooling.

Secondly; in terms of architectural style, the survey showed as already indicated in the above tables, that the modern-style villa has the highest WWR, which makes it a potential candidate for optimization.

Finally; the review showed that all nine villa types shared the same window construction details and the absence of shading design which makes any optimization scenario for the selected type applicable to others.

(Appendix –A presents the 5-Bedroom Villa construction drawings in more details)

4.9. Conclusion

Al Falah community, the case study was presented in this chapter. The review included the community planning and the housing in terms of allocation, typology, construction and sustainability measures.

The dominant type, the 5 bedroom villa was finally selected as the model for the window thermal performance optimization as a representative to houses within the community. The selected model thermal performance is presented in the next chapter as the first step of window thermal optimization.

5. CHAPTER FIVE: IMPACT OF ORIENTATION ON THE THERMAL PERFORMANCE OF THE EXISTING DESIGN; BASE CASE.

5.1. Introduction

This chapter is dedicated to the evaluation of the thermal performance of the existing design aiming to explore the impact of orientation in relation to windows in the five bedroom, modern style house, a dominant typology within Al Falah community. The existing design is considered as the base case and its detailed characteristics are presented in this chapter along with a review of the simulation tool's requirements, output and validity of use in this context.

5.2. Experimental Objectives and Method

The experimental objective of this part is to evaluate the impact of orientation (North, South, East, and West) on the existing windows thermal performance. The purpose of this initial evaluation is to verify the stated research problem which expects different building orientation with the current windows' specifications to yield variable thermal burdens on the building overall energy performance.

The experimental work was carried out through simulation. The selection of this testing method was necessary because on-site measurement of the existing design would have been a time-consuming process and would have included variables linked to the quality of the construction that would have been difficult to control and do not fall under the scope of this study. Further, it would have required access to houses of different orientations, an eventuality difficult to realize given the limited accessibility to the subject houses.

5.3. Experimental Procedure

The procedure of this experimental investigation includes identifying the existing building components, reviewing and selecting the testing tool then evaluating the thermal performance of the house in the four cardinal orientations.

5.3.1. Al Falah Five-bedroom Modern House; Existing Conditions

For this study, the typical modern style five-bedroom villa at Al Falah community was selected as a representative house type as described in chapter four (4.7). The total built area of the villa is 402 m^2, divided in two stories with a near square floor plan that included recesses and projections in several locations (Figures 5.1 & 5.2). Windows are distributed over the four façades, the front side displaying the highest window wall ratio of about 26%, while the rear, right, and left side facade have a WWR varying between 16.2%, 13.4% and 9.03% respectively (Table 5.1).

Windows of the base case are made of powder coated conventional aluminum frames with tinted low reflective double glass (Table 5.1).

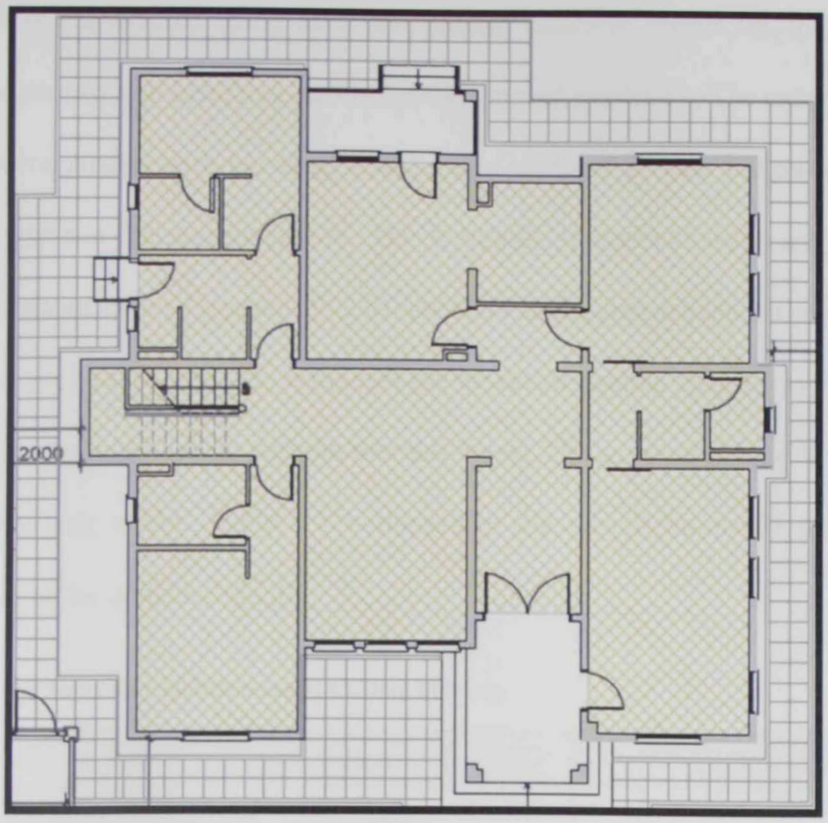


Figure 5.1: Typical Ground Floor Plan for the Five-bedroom Villa

Figure 5.2: Al Falah Typical Five-bedroom Villa (Modern Type): Base Case Model

The villa is constructed using insulated precast concrete panels for the external walls and precast non insulated panels for the internal partitions. The external walls have cement plaster with painting. The roof is made of precast hollow core slab with polystyrene thermal insulation. The R values of external walls and the roof were calculated using Opaque (V 2.0) software and equates respectively for the walls and roof to 11 and 18. Windows are made of double tinted low reflective glass in an aluminum frame without thermal break. The external main door is made of African teak wood. Table 5.1 summarizes the specifications of the exiting conditions of the considered villa.

Table 5.1: The Base Case; Specifications of Existing Building

Category	Item	Description
Site	Location	Abu Dhabi 24.42^0 N, 54.65^{0}E
Area	Total Built Area (GF+FF)	402.36 m^2 (4331 $ft^{2)}$
	Floor Area (Footprint)	212.56 m^2 (2288 ft^2)
	Overall Dimensions of the floor plan (Built up Area)	17* 15.85 m (56 * 52 ft).
Envelop Construction material	Windows	Double Tinted Low Reflective Glass with Air Gap+ Aluminum frame without thermal break.
	Wall	Insulated concrete panels. (20cm thick concrete panel with 6cm polystyrene insulation) R=11; Calculated using Opaque (Version 2) software based on the existing construction detail.
	Roof	Hollow core concrete slab with water proof and heat insulation layers R=18; Calculated using Opaque (Version 2) software based on the existing construction detail.
Ratio of Glazing per	Front Façade	26.55%

Façade	Right Side Façade	13.4%
	Left Side Façade	9.03%
	Rear Façade	16.2%
Air Conditioning System	Package Unit	Seasonal Energy Efficiency Rate (SEER)=13
Indoor Temperature	Lowest indoor comfort degree= 21.1 C (70F)	According to California Residential Code
	Highest indoor comfort degree= 23.88C (75F)	
Lighting	Illumination= 21.5 Lux (2foot candle)	
	Wall/ceiling reflectance=70%	Wall and colors range between white and cream (construction documents: ALDAR,2009)

5.3.2. Simulation Tool; Home Energy Efficient Design (HEED)

The investigation of the thermal performance of the villa was carried out through simulation, since this method presents multiple benefits: accuracy and ability to test multiple variables.

There are several softwares available for the evaluation of the building overall thermal performance. The Home Energy Efficient Design (HEED 4.0 build 34) software was selected for a number of reasons. First, the software is dedicated to skin loaded single zone building with homes being the specific target type, which is in line with our type of buildings (US Department of Energy, 2011). It is also available free of charge to use, and is user friendly.

HEED is a building energy analysis tool that evaluates the building overall thermal performance. It was developed by a research team led by Professor Murray Milne; from the Department of Architecture at the University of California in Los Angles

(UCLA). HEED is validated against the ASHRAE/BESTEST Standard 140 and the HERS BESTEST Standard (Henkhaus and Milne, 2012).

Generating a model to test with HEED requires basic inputs like location, floor area, number of stories. Floor plans can be drawn; windows and doors can be sized and dragged to place, and building basic characteristics can be selected from an extensive menu lists. The generated house model can be brought to the required orientation. Advanced input options are also available by entering data of variables including building thermal characteristics and systems (US Department of Energy, 2011).

HEED main outputs are in the form of annual energy consumption rates including electricity and fuel. Moreover; it provides the amount of CO_2 emissions, heat gain and loss in buildings. The advanced outputs include 3D charts with the ability to compare variables.

5.3.3. Simulation Process

In order to test the impact of orientation in the existing home design, Abu Dhabi weather data file was uploaded to the software to take into consideration the context of the study. The weather data file was obtained from the US Department of Energy website (US Department of Energy, 2012). Then, the above identified building characteristics were used to generate a computer baseline model for evaluation (Figure 5.3).

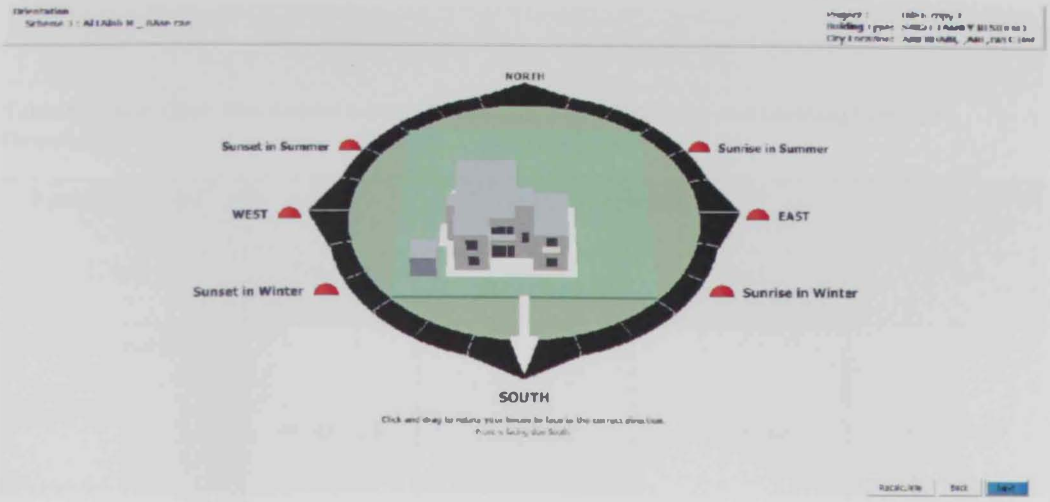


Figure 5.3: House Model using HEED (Base Case)

The testing included simulation for the four cardinal orientations by rotation of the model. Several types of results might be drawn from HEED. For the purpose of this study, the total annual energy consumption, cooling loads (Energy consumed for the purpose of cooling the building), and lighting loads (Energy consumed for the purpose of lighting the building) were the outputs considered as they are related to the impact of window thermal performance on whole building energy performance. The derived results were then analyzed through a comparison of outputs between orientations. (Appendix-B presents the whole simulation process including inputs and output).

5.4. Results and Analysis

The annual electrical energy consumption, cooling loads and lighting loads in Kwh for each cardinal orientation of the existing design are presented in Table 5.2. A first observation indicates a variable load for each orientation, highlighting the impact of window design on the total energy used (Figure 5.4).

Table 5.2: Base Case: The Annual Energy Consumption, Cooling loads and Lighting Loads per Orientation

Power Usage Kwh	Orientation			
	North	South	East	West
Total Annual Electrical Energy	46,087.18	46,048.50	43,200.68	47,393.95
Cooling Loads	29,455.98	29,434.24	27,163.91	30,400.48
Lighting Loads	1,677.42	1,671.27	1,868.10	1,714.18

Energy simulation for the base case has revealed a similar energy consumption rates when model is oriented either to the north or to the south. The west-facing model had the highest energy consumption rate, while the east oriented model had the lowest consumption rate (Figure 5.4).

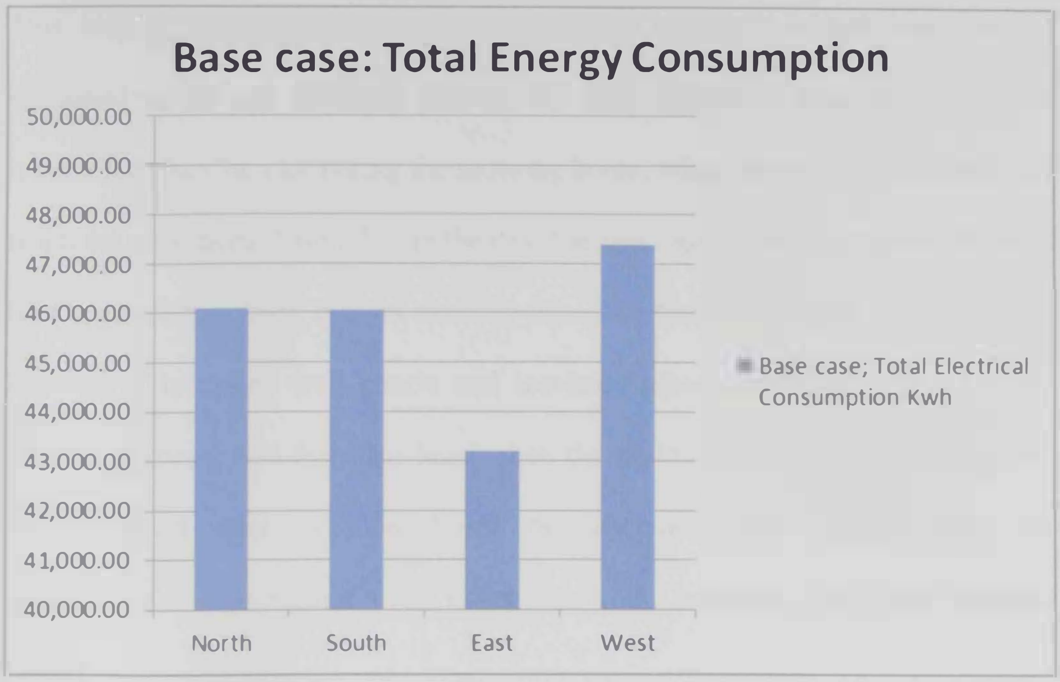


Figure 5.4: Total Electrical Energy Consumption for Base Case per Orientation

The recorded difference between the highest and the lowest consumption rate is 8.85%. This difference in annual electrical energy consumption is a result of a reduction in cooling loads as it is reduced by 10.65% when rotating building form west to face east (Figure 5.5).

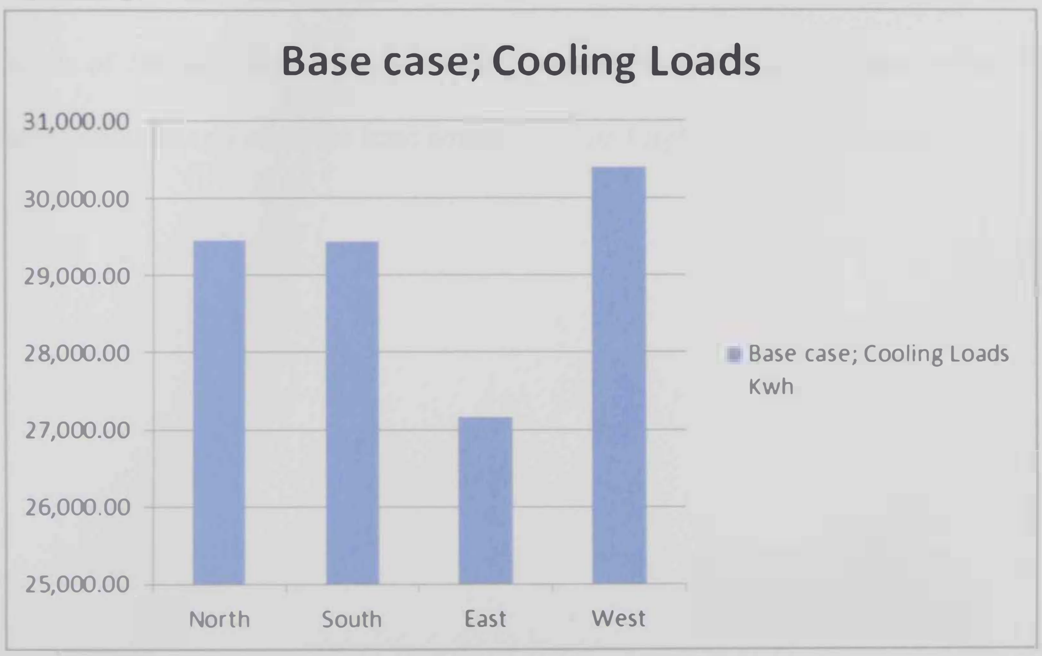


Figure 5.5: Base Case Annual Cooling Loads per Orientation

This reduction in cooling loads with the main facade oriented East can be explained as the east elevation receives the least amount of solar radiation. This radiation strikes the east during the morning hours, when temperature still does not reach the maximum. Later, during the day, the east façade heat gain comes through heat transmission from the hot ambient air. The transmitted heat was mitigated because of insulated wall panels and insulated glass panels used for windows (double glazing). On the other hand when the building is west facing, it starts to receive direct solar radiation during the afternoon until evening when the temperature is at its highest levels in addition to the transmitted heat from ambient hot air.

The lighting load indicates almost equal consumption when the building main façade is facing south or north (Table 5.2). When the building is facing west, there is a slight increase in lighting loads of about 2.5%. The eastern façade imposes an increase in lighting loads of about 9% when compared to the western one. The increase indicates the dependency on artificial lights for longer time due to lower levels of day light as the largest glazing area of the building is located to face the orientation that receives the least amount of direct light (Figures 5.5, 5.6).

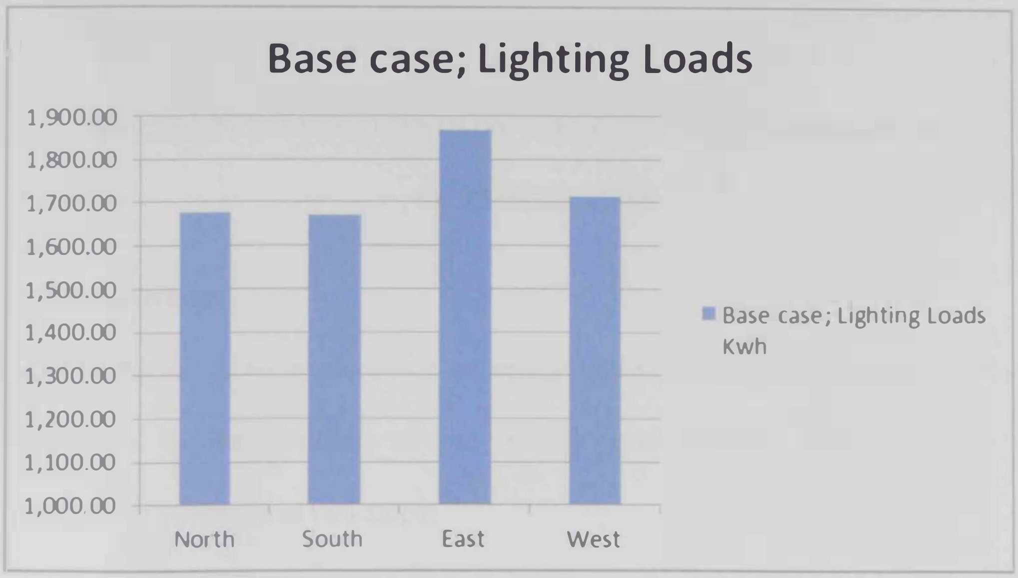


Figure 5.6: Base Case Annual Lighting Loads per Orientation

5.5. Conclusion

This chapter is aimed at evaluating the impact of orientation on windows thermal performance of the existing conditions: the base case. The testing was held using HEED; a computer simulation software. The simulation results highlighted a variable building energy performance for different orientations. The west-oriented model house has shown the highest rate of total energy consumption with an increase of 8.85% more than the east-facing which recorded the least consumption. This finding stresses the research hypothesis of finding a window specification that mitigates this orientation performance difference while providing potential energy savings.

Based on the impact of orientation on the annual energy consumption of the existing house design, the next chapter is set out to explore the potential of thermal performance optimization through optimum window's specifications.

6. CHAPTER SIX: WINDOW THERMAL PERFORMANCE OPTIMIZATION

6.1. Introduction

This chapter aims to explore the potential contribution of optimized window components to the building overall energy performance. This experimental investigation proceeds in two steps:

- The first step consists of testing alternatives based on the optimization of one single variable of the window material.
- The second step builds on the first and consists of testing alternatives based on combined optimized variables.

The objectives of this stage of the experimental investigation can be stated as follows: first; to evaluate the impact of a single window component such as glass, frame or shading on the overall building energy performance at each building orientation. Second; to evaluate the impact of optimized combined window components, on the overall building energy performance at each building orientation.

The main purpose of this procedure is to explore window specifications that provide optimum thermal performance for all orientations as well as identify the most critical window component. The testing procedure is similar to the one carried out for the existing design as presented in Chapter 5.

6.2. Selection of Optimum Window Components

Window thermal performance optimization can be achieved through a number of window design parameters. These include window size, material and shading. However, changing the size of the window will influence the existing façade design. Hence, the window size in this study was kept as per the existing design. In addition, the external shading in the form of overhangs and fins were not considered as they will invariably affect the architectural style as well as require some design change, which will be contradiction with the research main objective. Consequently, the variables included the window material (glass and frame) and external automated slatted blinds shading. The latter was selected to suit the variable housing orientations since fixed external shading adapted to each orientation requires multiple design solutions and affect the architectural appearance of houses. The orientation being the independent variable.

6.2.1. Window Components Optimization

The selection of window components was based on two factors. First, a selection based on the improved thermal performance of the evaluated element. Second, consideration was given to the availability of the selected material or components in the local market.

6.2.1.1. Glass

The literature review in Chapter three (3.5.3) indicated that Low E glass should be a better performing glass than the existing tinted glass based on its thermal characteristics (U value and SHGC). Hence, the following glass components were selected for evaluation:

- Double Low E glass that consists of two glass panes with an air space. The inner face of the outer pane is coated with Low E material.
- Double squared Low E Glass with two Low E coatings; one at inner surface of outer glass and the other at the outer face of the inner pane)
- Double- reflective glass that consists of two-glass panes with reflective coating on the outer one.

Table 6.1 presents the thermal characteristics of the selected glass types (ASHRAE, 2007).

Table 6.1: Glass Alternative and their Thermally Improved Characteristics.

Glass Type	U Value	SHGC	Tvis
Tinted double-pane glass (Existing Design)	0.81	0.45	0.57
Tinted double-pane Low E glass	0.69	0.39	0.53
Tinted double-pane Low E squared glass	0.67	0.25	0.38
Tinted double-pane reflective glass	0.81	0.16	0.09

6.2.1.2. Window Frame

In addition to glass, a vinyl frame was considered as it offers a better thermal insulation when compared to traditional aluminum frames as well as its availability in the market. The usage of vinyl improves the thermal properties as show in Table 6.2:

Table 6.2: Windows Thermal Characteristics: Aluminum Versus Vinyl Frame

	U Value	SHGC	Tvis
Tinted double-pane glass in aluminum frame (Existing Design)	0.81	0.45	0.57
Tinted double-pane glass in vinyl frame	0.51	0.38	0.49

6.2.1.3. Shading

In terms of window shading, the external operable slatted blinds were selected for implementation on all windows. These automated slatted blinds are light colored venetian blinds that close if the sun is on the window and interior temperature is above the set comfort level. The blinds are either fully open or fully closed. The selection of this type of automated blinds meets two requirements. First, they can be adjusted to suit the variation in orientation in residential neighborhoods similar to the one under study, with thousands of houses allocated in different orientations that otherwise would have required specific shading designs for each orientation. Second, it maintains a distinctive uniformity as a specific orientation based design would have conflicted with the research objectives that aim at maintaining the architectural appearance of houses. Although, it is an added element, the same element will potentially be implemented in all windows.

6.3. Testing Optimized Windows

This part presents the results of testing thermal performance of house with optimized windows components. The process includes optimized glass, optimized frame and external shading device in a form of automated external slatted blinds applied for all windows.

6.3.1. Glass Thermal Optimization

The selected glass types were analyzed using HEED for their impact on the overall thermal performance of house in relation to the four cardinal orientations. Table

6.3 presents the outputs of testing the alternatives compared to the base case (double tinted low reflective glass).

Table 6.3: The Impact of Optimized Glass Alternatives on Total Annual Electrical Energy Consumption

Variable		North	South	East	West
Base case	Total (kwh)	46,087.18	46,048.50	43,200.68	47,393.95
Tinted, Double, Low E Glass	Total (kwh)	44,626.92	44,580.91	42,225.15	45,709.24
	Reduction	3.17%	3.19%	2.26%	3.55%
Tinted, Double, Squared Low E Glass	Total (kwh)	43,072.78	43,045.74	41,846.74	43,663.94
	Reduction	6.54%	6.52%	3.13%	7.87%
Double Reflective Glass.	Total (kwh)	44,665.09	44,616.05	43,573.18	44,869.22
	Reduction	3.10%	3.11%	-0.86%	5.33%

The results show that the highest savings in total annual energy consumption were obtained with all orientations when using the double tinted squared Low E glass. The savings were from almost 8% in the case of west-facing house, 6.5% for the north and South and 3% in the case of east-facing home (Table 6.3& Figure 6.1).

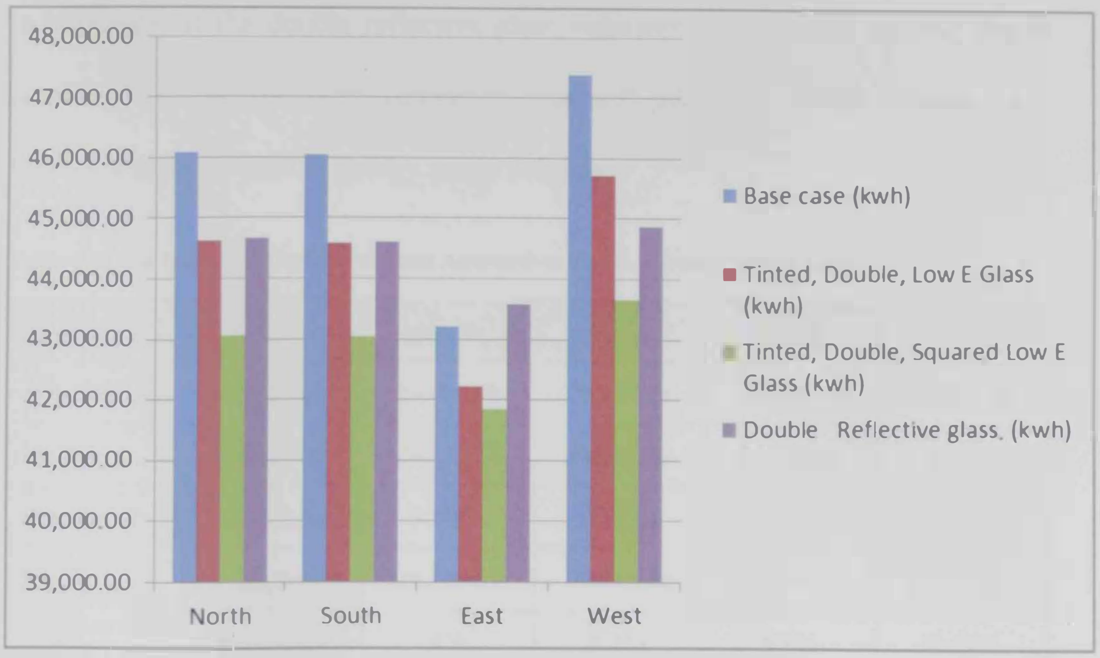


Figure 6.1: The Impact of Optimized Glass Alternatives on the Total Annual Electrical Energy Consumption

However, the total annual electrical consumption does not distinguish the differential impact for lighting and cooling usage. A break-down of the total annual energy consumption to cooling loads and lighting loads enables us to obtain a better understanding of impacts.

For instance, the total annual energy consumption for the house with tinted doubled Low E glass at windows reveals that there was a significant saving in cooling loads, indicating a better heat control. Savings ranged from about 6% to 10%, by comparison to the base case (Table 6.4 & Figure 6.2). However, in the case of the house with double reflective glass, lesser savings were observed because of the excessive lighting loads which ranged between 110% and 130%. These excessive lighting loads are due to the low visible transmittance of the reflective glass which led to an increased dependency on artificial lighting (Table 6.5 & Figure 6.3).

In summary, if the double reflective glass indicates a better heat control, this is countered by its low light admission that will adversely affect lighting load, leaving a negative annual energy usage balance.

Table 6.4: The Impact of Optimized Glass Alternatives on the Annual Cooling Loads

		North	South	East	West
Base Case	Total (kwh)	29,455.98	29,434.24	27,163.91	30,400.48
Tinted, Double, Low E Glass	Total (kwh)	28,325.34	28,299.51	26,366.25	29,103
	Reduction	**3.84%**	**3.85%**	**2.94%**	**4.27%**
Tinted, Double, Squared Low E Glass	Total (kwh)	26,793.57	26,763.44	25,593.44	27,200.73
	Reduction	9%	9.1%	5.8%	10.52%
Double Reflective Glass.	Total (kwh)	26,737.02	26,705.51	25,892.90	26,902.41
	Reduction	**9.20%**	**9.30%**	**4.70%**	**11.50%**

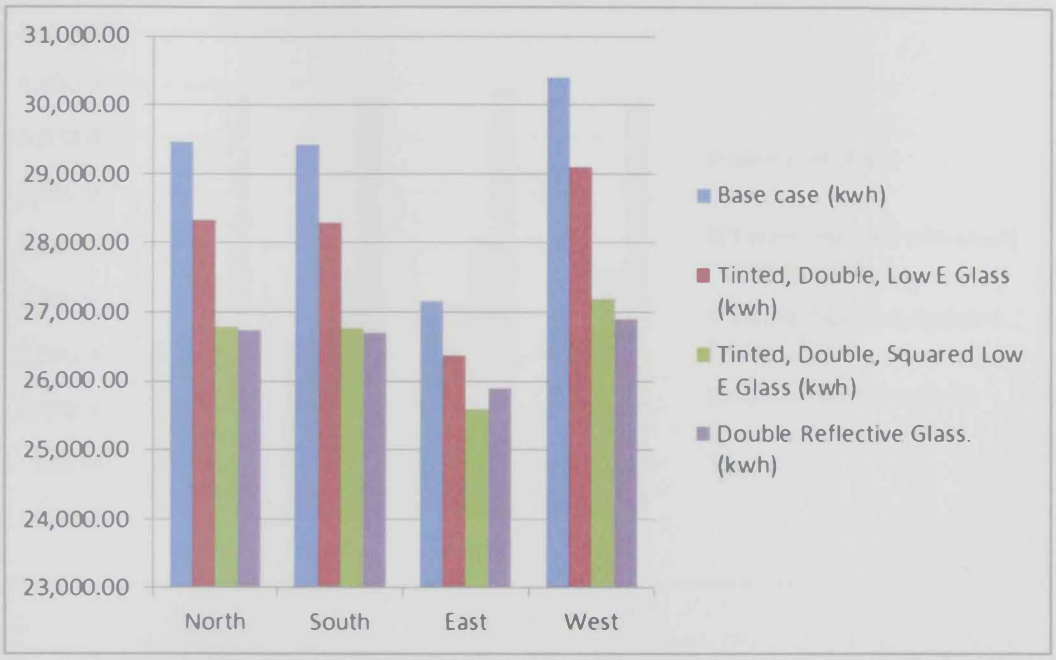


Figure 6.2: The Impact of Optimized Glass Alternatives on the Annual Cooling Loads

Table 6.5: The Impact of Optimized Glass Alternatives on the Annual Lighting Loads

		North	South	East	West
Base Case	Total (kwh)	1,677.42	1,671.27	1,868.10	1,714.18
Tinted, Doubled with Low E coating.	Total (kwh)	1,740.20	1,731.31	1,968.51	1,776.83
	Increase	3.75%	3.60%	5.37%	3.65%
Tinted, Doubled, Squared , Low E	Total (kwh)	2,243.91	2,258.52	2,629.08	2,287.93
	Increase	33.77%	35.14%	40.73%	33.5%
Double Reflective Glass	Total (kwh)	3,907.59	3,901.65	3,948.64	3,889.25
	Increase	132.95%	133.45%	111.40%	126.90%

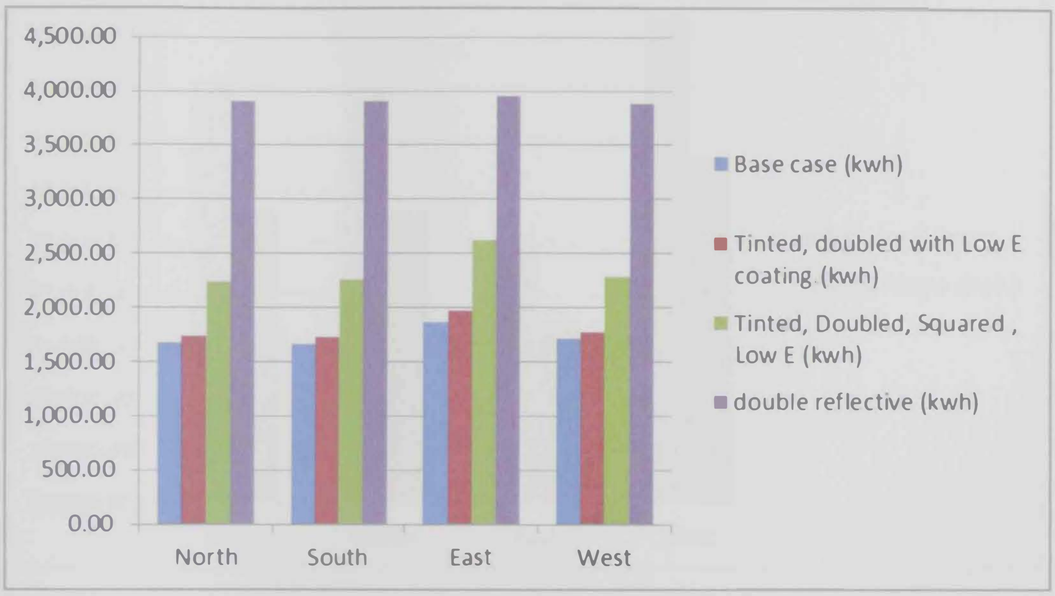


Figure 6.3: The Impact of Optimized Glass Alternatives on the Annual Lighting Loads

6.3.2. Window Frame Thermal Optimization

The test results of alternative house with thermally improved frame reveal that by replacing the existing window frame material to with vinyl, a 4-6% saving in the overall energy consumption can be obtained. The least amount of savings was obtained with the east orientation while the highest savings were with the west orientation (Table 6.6& Figure 6.4). This difference refers to the amount of solar radiation including direct and transmitted heat, received in each orientation.

Table 6.6: The impact of Optimized Frame (Vinyl) on the Total Annual Electrical Energy Consumption

Variable	North	South	East	West
	Total	Total	Total	Total
Base Case (Aluminum without thermal break)	46,087.18	46,048.50	43,200.68	47,393.95
Vinyl Frame	43,624.49	43,571.62	41,464.14	44,664.79
Reduction	5.35%	5.38%	4%	5.76%

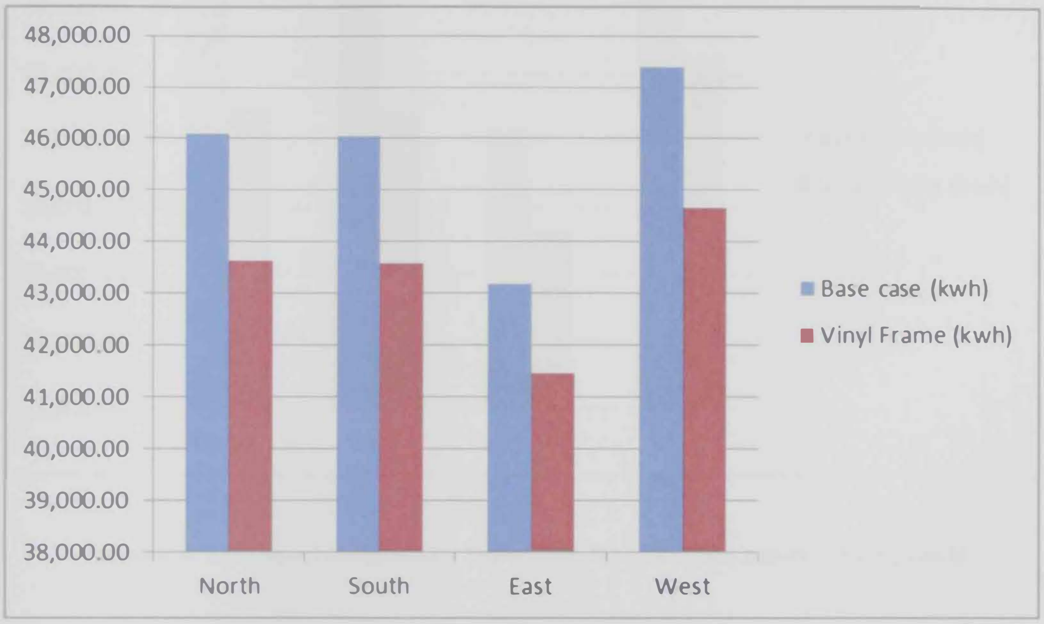


Figure 6.4: Vinyl Frame Versus Aluminum (Base Case): Total Annual Electrical Energy Consumption

The total annual energy loads analysis shows that there was a measurable reduction in cooling loads ranging between 5.5% and 7% (Table 6.7 & Figure 6.5). These reductions were due to a better U Value of the vinyl frames that improved the overall window resistance to heat gain.

Table 6.7: The Impact of Optimized Frame (Vinyl) on the Total Annual Cooling Loads

Variable	Cooling Kwh	Cooling Kwh	Cooling Kwh	Cooling Kwh
	North	South	East	West
Base case	29,455.98	29,434.24	27,163.91	30,400.48
Vinyl Frame	27,514.41	27,486.92	25,662.85	28,262.02
Reduction	6.60%	6.60%	5.52%	7%

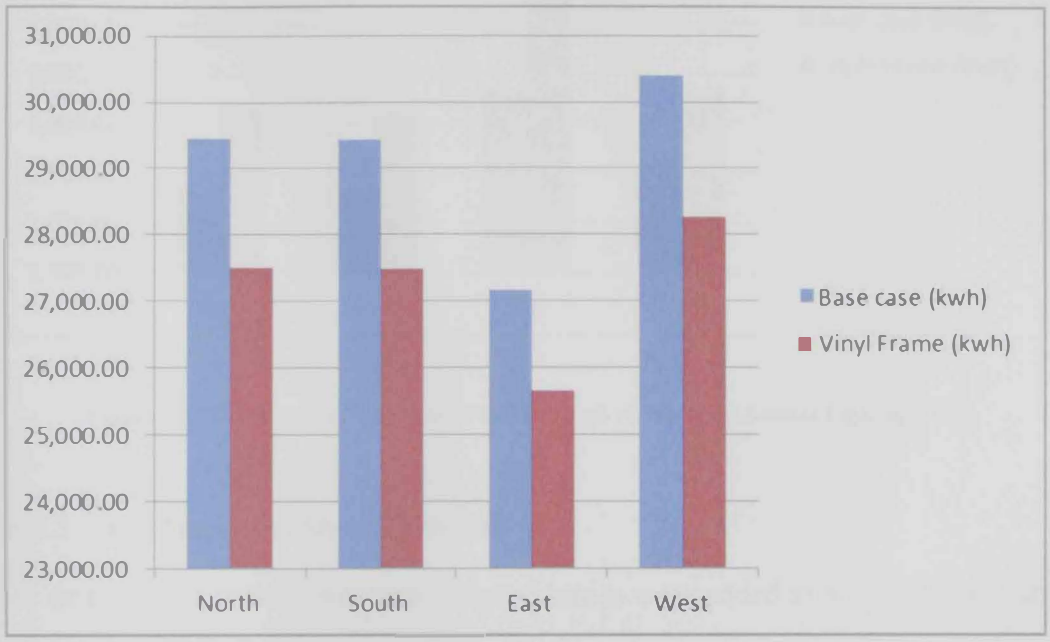


Figure 6.5: The Impact of Optimized Frame (Vinyl) on the Total Annual Cooling Loads

Lighting loads experienced an increase that ranges between 13.4% for the east orientation to around 8% for the north, south and west orientations (Table 6.8 and Figure 6.6).

Table 6.8: The Impact of Optimized Frame (Vinyl) on the Total Annual Lighting Loads

Variable	Light Kwh	Light Kwh	Light Kwh	Light Kwh
	North	South	East	West
Base Case	1,677.42	1,671.27	1,868.10	1,714.18
Vinyl Frame	1,833.01	1,819.72	2,157.85	1,868.76
Increase	8.50%	8.17%	13.43%	8.30%

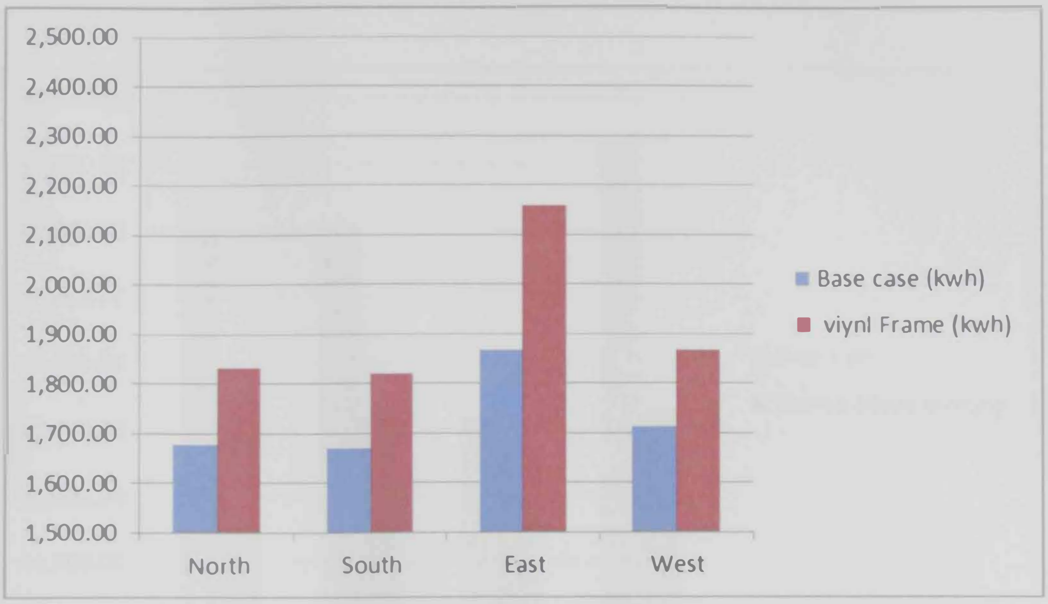


Figure 6.6: The Impact of Optimized Frame (Vinyl) on the Total Annual Lighting Loads

6.3.3. The Impact of Shading Device

At this stage of testing, automated slatted blinds were added to all windows in the base case design. Results have shown reduction of about 6% in north, south, and west orientation, while, only 1.10% of reduction in energy consumption was achieved in the eastern orientation (Table 6.9 & Figure 6.7).

Table 6.9: The Impact of Shading on the Total Annual Electrical Energy Consumption

Variable	North kwh	South kwh	East kwh	West kwh
	Total	Total	Total	Total
Base Case	46,087.18	46,048.50	43,200.68	47,393.95
Slatted Blinds Shading	43,444.58	43,215.89	42,726.89	43,308.39
Reduction	5.73%	6.15%	1.10%	6.62%

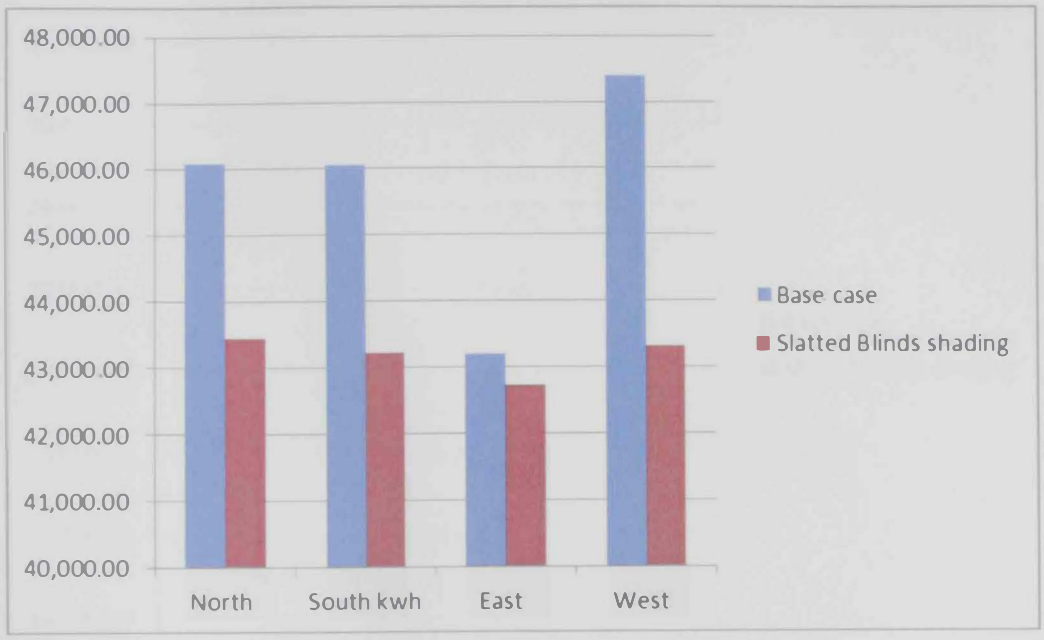


Figure 6.7: The Impact of Shading on the Total Annual Electrical Energy Consumption

As anticipated the slatted blinds shading acted as heat control element providing saving in cooling loads ranging from 3 to 12% for all orientations. (Table 6.8 and Figure 6.8).

Table 6.10: The Impact of Shading on the Total Annual Cooling Loads

Variable	Cooling Kwh	Cooling Kwh	Cooling Kwh	Cooling Kwh
	North	South	East	West
Base Case	29,455.98	29,434.24	27,163.91	30,400.48
Slatted Blinds Shading	26,837.68	26,748.39	26,301.83	26,791.49
Reduction	8.90%	9.10%	3.17%	11.90%

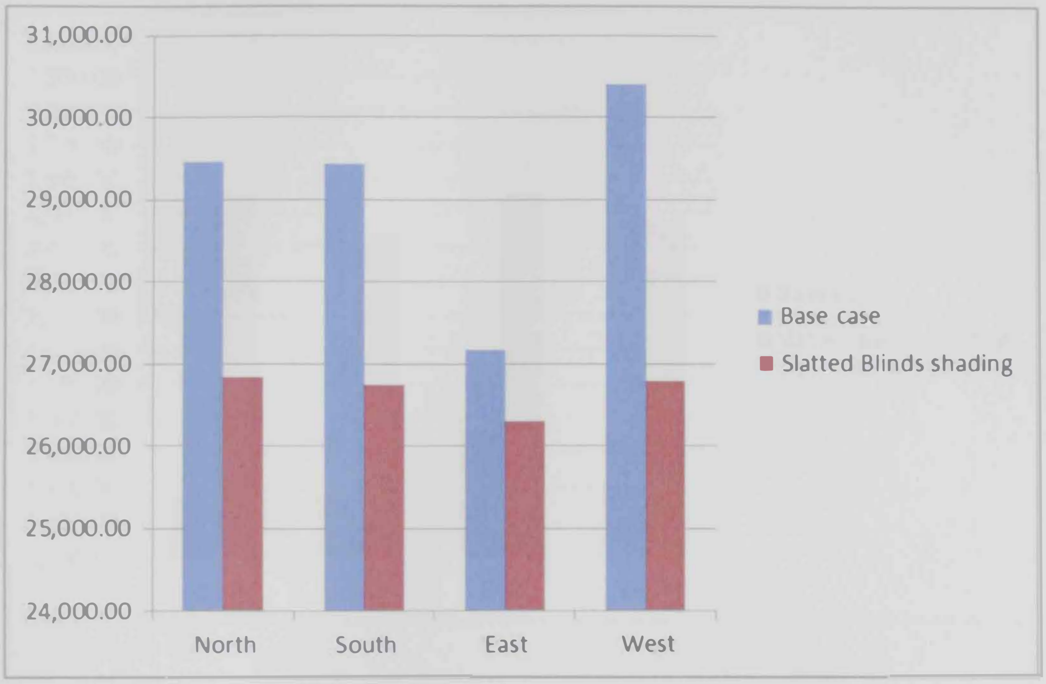


Figure 6.8: The Impact of Shading on the Total Annual Cooling Loads

Lighting loads, on the other hand, increased significantly by about 36 to 50%, with the highest rate at the north and south orientations (Table 6.11 & Figure 6.9). This increase was due to the limited amount of daylight allowed by the slatted blinds and the consequent reliance on artificial light.

Table 6.11: The Impact of Shading on the Total Annual Lighting Loads

Variable	Light Kwh	Light Kwh	Light Kwh	Light Kwh
	North	South	East	West
Base Case	1,677.42	1,671.27	1,868.10	1,714.18
Slatted Blinds Shading	2,551.78	2,443.48	2,553.14	2,477.63
Increase	52.12%	46.20%	36.70%	44.54%

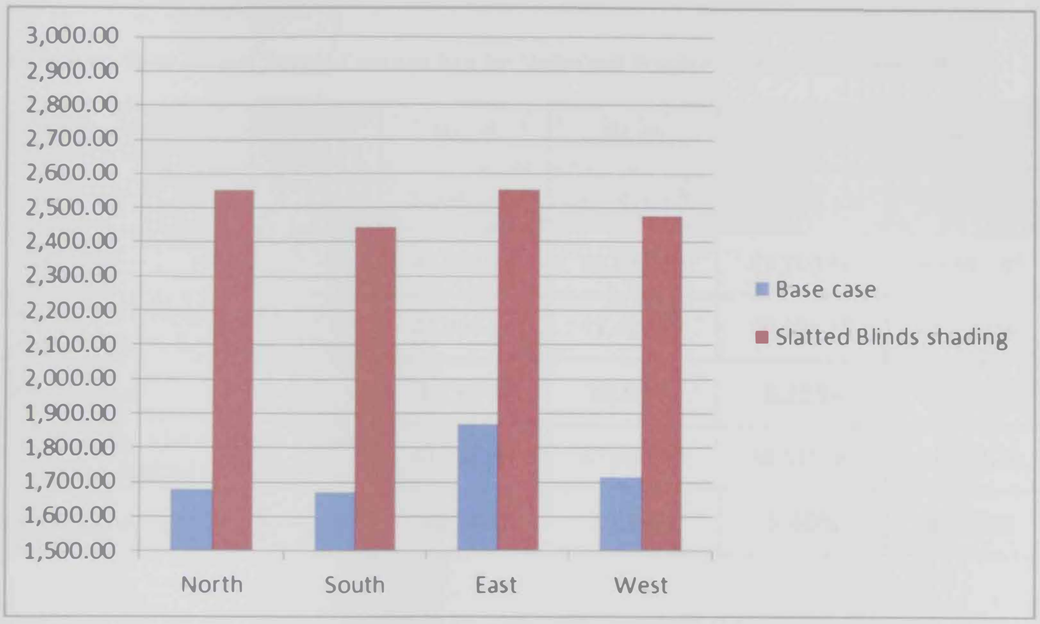


Figure 6.9: The Impact of Shading on the Total Annual Lighting Loads

6.4. Optimization of Window Systems

Based on the results obtained from single window components optimization, two optimization scenarios were generated using a combination of the most efficient components. The first scenario was generated by assembling the vinyl frame with squared Low E double tinted glass while the second scenario was to integrate vinyl frame with Low E glass in presence of external shading in the form of automated slatted blinds.

Testing outputs of the two scenarios have shown significant savings in overall building energy consumption with 6 to 11.7% of savings with Scenario 1 and 6.4 to 13% with Scenario 2 (Table 6.12 & Figure 6.10). The highest saving rates were obtained for the west orientation for both optimization scenarios, with about 11.72% for Scenario 1 and 13.26% for Scenario 2. However, the lowest rate of savings was obtained for the east orientation with approximately 6% for both scenarios (Table 6.12 & Figure 6.10).

Table 6.12: Total Annual Energy Consumption for Optimized Window Systems (Scenarios 1&2)

Variable	North	South	East	West
	Total kwh	Total kwh	Total kwh	Total kwh
Base Case	46,087.18	46,048.50	43,200.68	47,393.95
Scenario 1: Tinted, Double, Squared, Low E+ Vinyl Frame	41,407.96	41,429.77	40,551.88	41,839.04
Reduction	**10.15%**	**10.03%**	**6.13%**	**11.72%**
Scenario 2: Vinyl Frame +Low E Glass+ Slatted Blinds	41,136.40	41,046.99	40,439.36	41,107.56
Reduction	**10.74%**	**10.86%**	**6.40%**	**13.26%**

The results presented in Table 6.12 and Figure 6.10 reveals similar energy consumption rates for all building orientation for both scenarios, which strongly underlines the objective of this research.

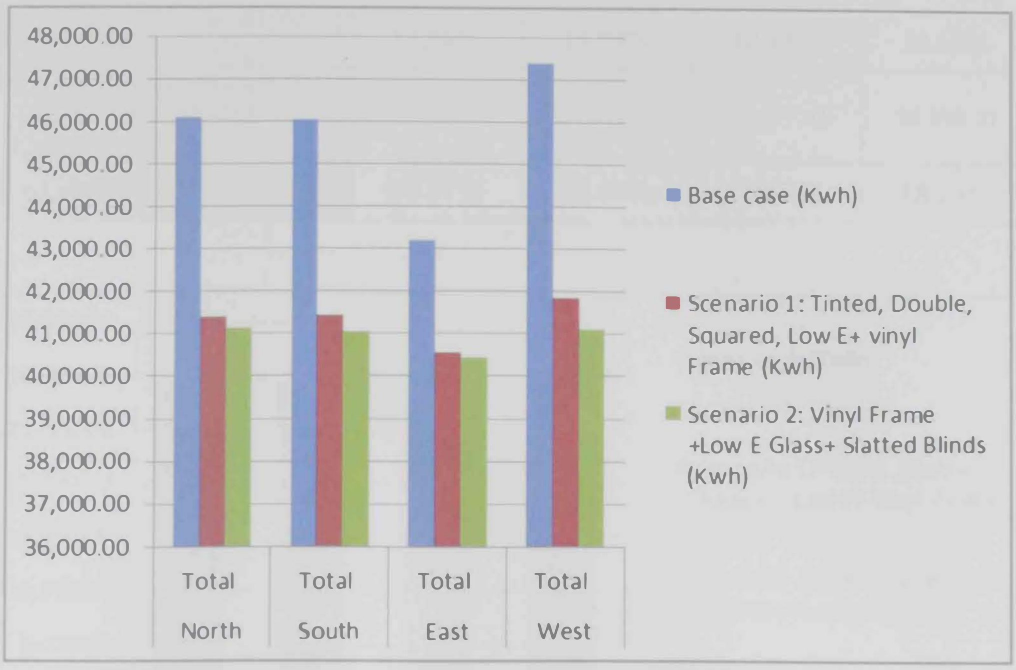


Figure 6.10: Total Annual Energy Consumption for Optimized Window Systems (Scenarios 1&2)

The differentiation between cooling loads and lighting loads from the annual energy consumption provides a more detailed view of the thermal behavior of the optimized window systems.

Cooling loads for both scenarios, presented in Table 6.13 and Figure 6.11, indicate reductions in cooling loads ranging between 10% and 16.65% for Scenario 1 and between 10% and 18% for Scenario 2. The west orientation also has recorded the highest amount of saving in cooling loads for both scenarios with about 16.65% for scenario 1 and 18% for scenario 2.

Table 6.13: Annual Cooling Loads for Optimized Window Systems (Scenarios 1&2)

Variable	Cooling North	Cooling South	Cooling East	Cooling West
Base Case (Kwh)	29,455.98	29,434.24	27,163.91	30,400.48
Scenario 1:Tinted, Double, Squired, Low E+ Vinyl Frame (Kwh)	25,342.82	25,320.19	24,413.40	25,642.43

Reduction	**13.96%**	**13.98%**	**10.12%**	**15.65%**
Scenario 2:Vinyl Frame +Low E Glass+ Slatted Blinds (Kwh)	24,898.64	24,841.16	24,357.41	24,888.07
Reduction	**15.47%**	**15.60%**	**10.33%**	**18.13%**

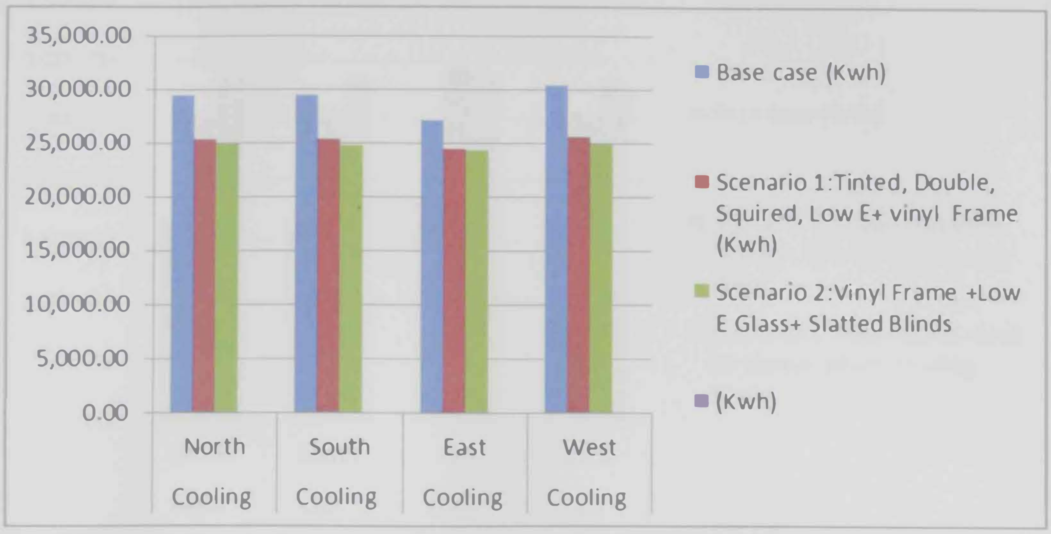


Figure 6.11: Annual Cooling Loads for Optimized Window Systems (Scenarios 1&2)

On the other hand, in both scenarios lighting loads increased considerably. The increase ranged in Scenario 1 from around 50% compared to the base case. The increase in Scenario 2 ranged between 55% and 70% (Table 6.14 & Figure 6.12). This increase is justified by the increase of reliance on artificial light because of usage of multi-coated glass in Scenario 1 and shading in Scenario 2.

Table 6.14: Annual Lighting Loads for Optimized Window Systems (Scenarios 1&2)

Variable	**Light**	**Light**	**Light**	**Light**
	North	**South**	**East**	**West**
Base case (Kwh)	1,677.42	1,671.27	1,868.10	1,714.18
Scenario 1:Tinted , Doubled, Squired, Low E+ Vinyl Frame (Kwh)	2,537.04	2,589.88	2,928.55	2,565.32
Increase	**51.24%**	**54.90%**	**56.76%**	**49.65%**

Scenario 2: Vinyl Frame +Low E+ Slatted Blinds Shading (Kwh)	2,861.32	2,849.28	2,890.73	2,846.55
Increase	**70.60%**	**70.50%**	**54.75%**	**66.05%**

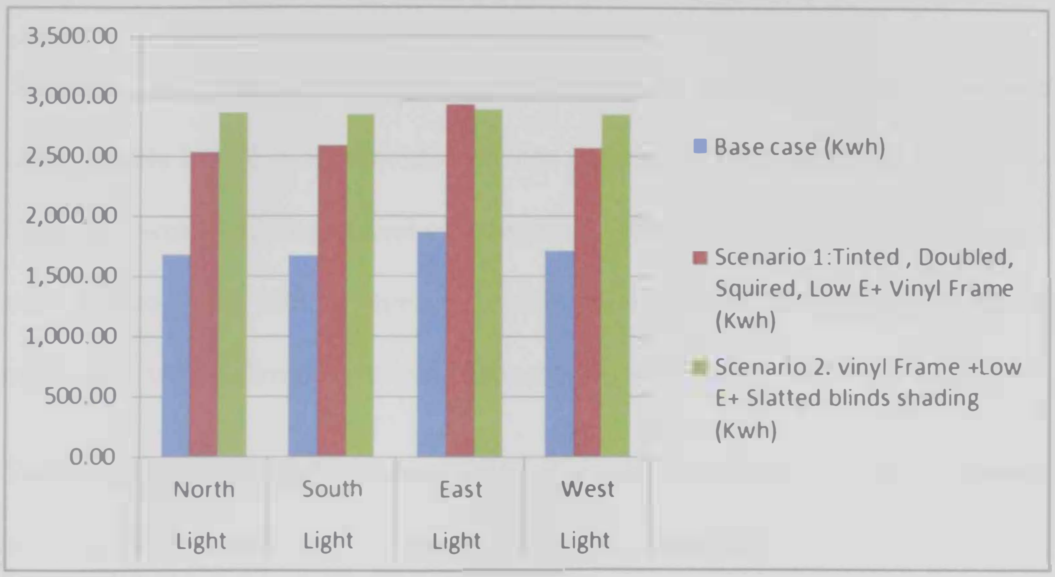


Figure 6.12: Annual Lighting Loads for Optimized Window Systems (Scenarios 1&2)

6.5. Analysis and Discussion

The results of the experimental investigation highlight two important aspects that serve well the objectives of this study. The first aspect stresses the importance of window material optimization in terms of energy savings and mitigating the building orientation impact. While the second aspect deals with thermal effectiveness of single optimized components that facilitates affordable solutions for an existing constructions.

6.5.1. The Impact of Optimized Window Systems

In summary, tests analysis of the optimized window systems revealed an improved overall building thermal performance with measurable energy savings ranging from 6% to 11.7% for the east and west orientations respectively using a vinyl frame with double squared tinted Low E glass. More importantly is the reduced difference in terms of annual energy consumption between orientation. The variation of the thermal performance between orientations ranged from 1 to 3% compared to 8.85% between east-facing and west-facing house in the base case.

Similarly, the addition of external automated slatted blinds to a vinyl frame with tinted double Low E glass provided savings ranging between 6.5% and 13% of the building overall building annual consumption. Here too, the impact of orientation was reduced and similar energy consumption rate were achieved with all orientation with differences ranging between 1% and 3%.

These findings highlight the opportunity of specifying advanced window material such as multi-coated Low E glass, poor heat conducting frames like vinyl or integration of automated external shading to mitigate the thermal impact of orientation. Moreover, it opens possibilities for improved thermal performance along with flexibility in the site planning and architectural design of governmental housing projects independently from the orientation heat impact.

6.5.2. The Impact of Window Single Component

In addition, the comparison of single optimized window components tests showed a variation in the effectiveness of the tested elements in terms of thermal performance. The comparison presented in Table 6.15, exposed that the use of the tinted double squared low E glass was able to provide the highest rate of saving that ranged between 3.13% for the north and South, slightly over 6% for the east and almost 8% for the west as compared to the base case.

Table 6.15: Impact of Single Optimized Window Component on Annual Energy Consumption

	North	South	East	West
Tinted double Low E Glass	3.17%	3.19%	2.26%	3.55%
Tinted Double Squared Low E Glass	6.54%	6.52%	3.13%	7.87%
Vinyl Frame	5.35%	5.38%	4%	5.76%
Automated Slatted Blinds	5.73%	6.15%	1.10%	6.62%

The use of vinyl frames follows that with reduction in overall energy consumption ranging from 4% to 5.76% (Table 6.15), which is considered to be measurable savings. These savings are associated with similar thermal performance with the variable orientations.

These findings open the opportunity for affordable optimization for existing similar construction or in the case of projects with limited budget. In addition, in the case of retrofitting existing building, there is a clear indication which window component should be given priority to yield measurable energy savings.

6.6. Conclusion

This chapter presented the experimental investigation of the window thermal optimization in relation to orientation. The process went through two main stages. First, window components (glass, frame and shading) were individually optimized while second consisted of generating two optimized window systems or combination scenarios.

The first scenario included optimum glass and frame by using double squared Low-E tinted glass and vinyl frame. The total annual energy savings ranged from 6 to 11.7% from mte east and west orientation with similar consumption rates for all orientations. The second scenario included optimized glass. frames and automated slatted shading devices and achieved a 6.5% to 13% energy savings for the east and west orientation respectively with limited energy consumption variation between orientation. However, the use of automated slatted blinds as a shading device is associated with higher maintenance and operational costs.

7. CHAPTER SEVEN: CONCLUSION

This research intends to be a contribution to the growing interest and increased focus on energy savings in the built environment and the depletion of natural resources. The main scope of this research was to achieve an optimal window thermal performance that suits variable orientations in governmental housing projects. The target was also to achieve the optimal thermal performance through the improvement of thermal specifications of window components rather than to impose additional elements to window design such as external shading devices that may interfere with the original architectural style. The type of glass, the frame and the shading device were the scope of the thermal optimization process.

The study was initiated through a review of the historical development of housing programs in the UAE, considering housing typology, construction and sustainability measures. Al Falah community, the housing case study, was considered as a representative governmental housing program. An analysis of housing typology, size, architectural style and construction details was carried out and enabled to identify a representative house. The review highlighted the representative typology in the form of a five bedroom detached house based on frequency of occurrence. This was considered as the base case for the investigation. Concurrently a review of residential window green design principles was carried out in order to support the window thermal optimization process.

The experimental investigation was based on computer simulation using the Home Energy Efficient Design (HEED) software. The initial evaluation of the thermal performance of the existing design conditions highlighted the impact of window orientation on the building overall thermal performance. The west orientation yielded 8.85% more annual energy consumption than the east orientation and 3%

more than the north and south orientations, confirming the problem statement that the orientation has an impact on the thermal performance of the house.

Next, the window thermal optimization process considered first single window component. Glass in the form of double-tinted squared Low E, double-tinted Low E and double reflective , a vinyl frame and automated slatted blinds were tested. The results have shown the effectiveness of double-tinted squared Low E glass in achieving measurable savings that ranged from 8% for the west-facing house, to 3% for the east-facing house, while north and south facing houses savings ranged around 6%. The use of vinyl frame have resulted in savings around 5% with all building orientations.

Then, optimized window systems were considered based on the previous output and included two window systems: double-tinted squared Low E glass with a vinyl frame and double-tinted Low E glass, vinyl frame and external slatted blinds.

The result of the first scenario (Double-tinted Squared Low E with Vinyl Frame) revealed improved and similar energy consumption for all building orientations. The annual energy consumption was 6% for east-facing building to 11% for west facing building lower than the existing design.

The double-tinted Low E glass with vinyl frame and automated slatted blinds have shown an improved thermal performance with saving ranging between about 6% for east-facing building to 13% for west-facing building of the total annual electrical energy consumption. However, the second alternative is considered impractical due to the maintenance required by the automated slatted blinds. Hence, the usage of thermally efficient window glazing along with thermally efficient frame can provide an improved similar thermal performance for all building orientations.

It should be stressed that the validity of the results remain tributary of the data considered and the evaluation method used and may need further validation.

Finally, window thermal optimization in houses can be considered as a one-step further towards obtaining thermal efficiency. However, there is still a wide range of research possibilities associated with window thermal optimization. Air infiltration is a potential research topic, which is associated with the window installation process and would affect its thermal performance.

Further research possibilities that increase the thermal efficiency of the houses, lay in the area of envelop components optimization other than windows such as roof and exterior walls. Lighting and HVAC equipment efficiency can provide additional options for an improved building thermal efficiency. There is still a scope that this research leaves for future investigation. This scope includes the cost-benefit analysis for the usage of thermally improved glass types available in the UAE construction market.

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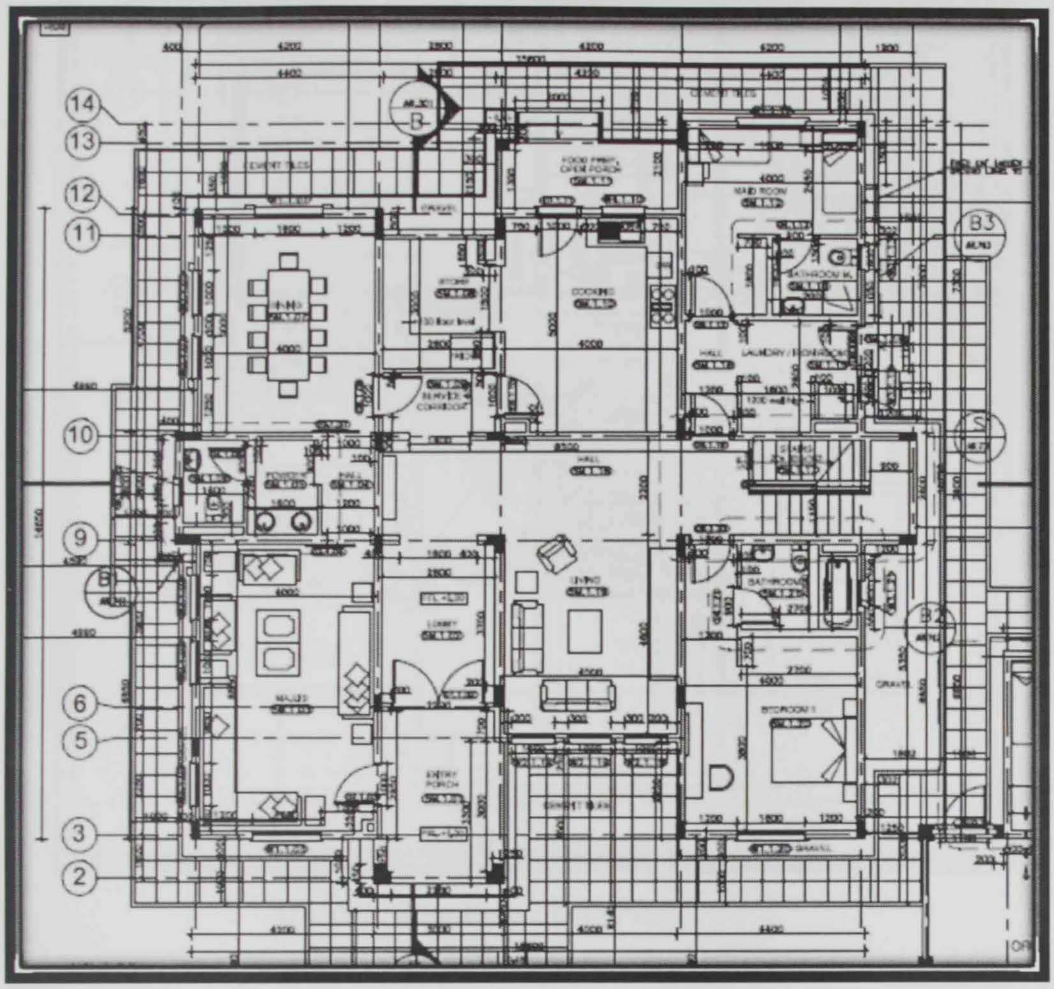
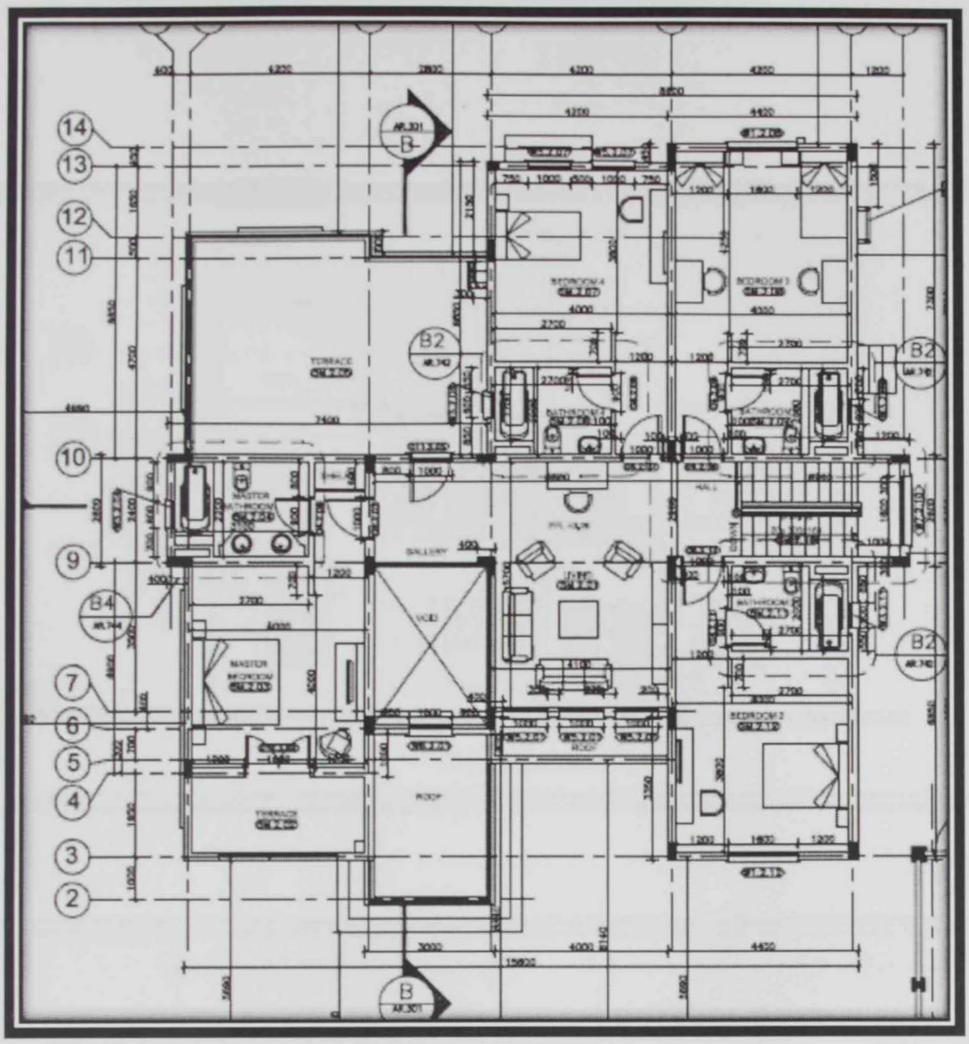
Appendix A

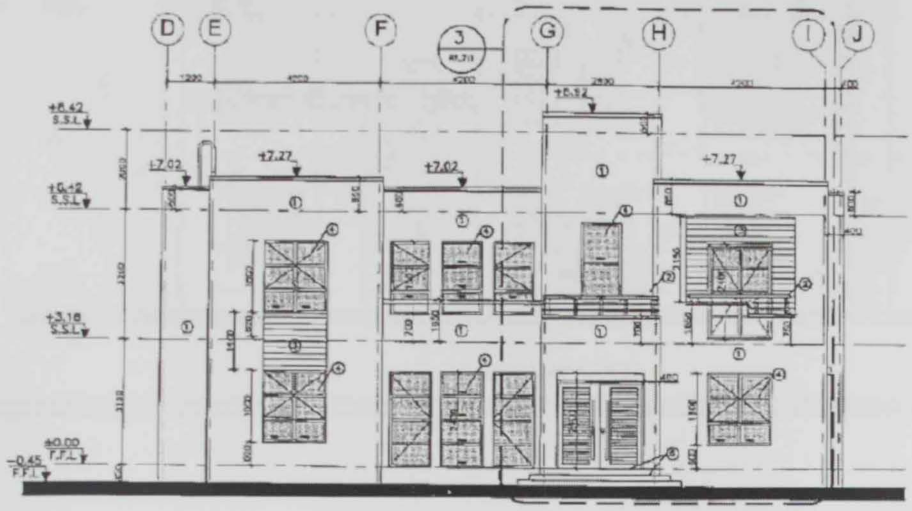
Al Falah Villa Architectural Drawings, the Modern Type



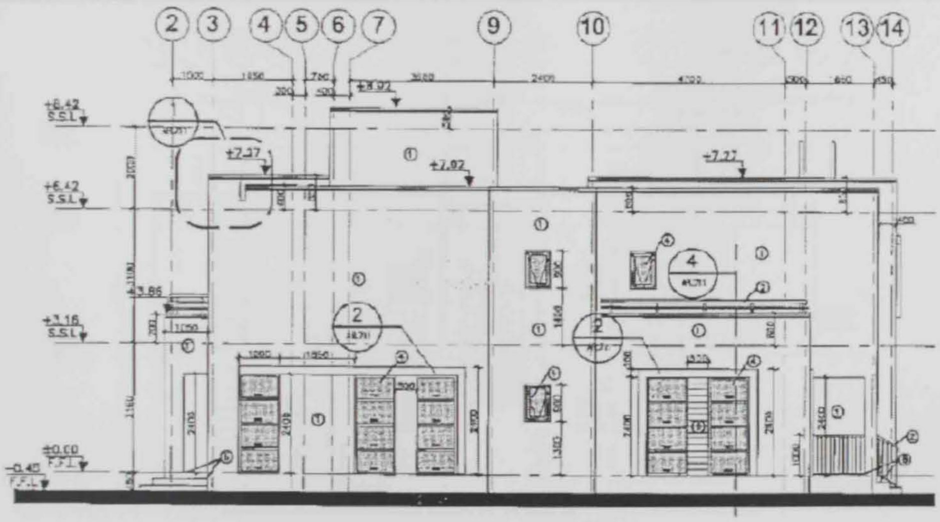
Al Falah Villa Ground Floor Plan



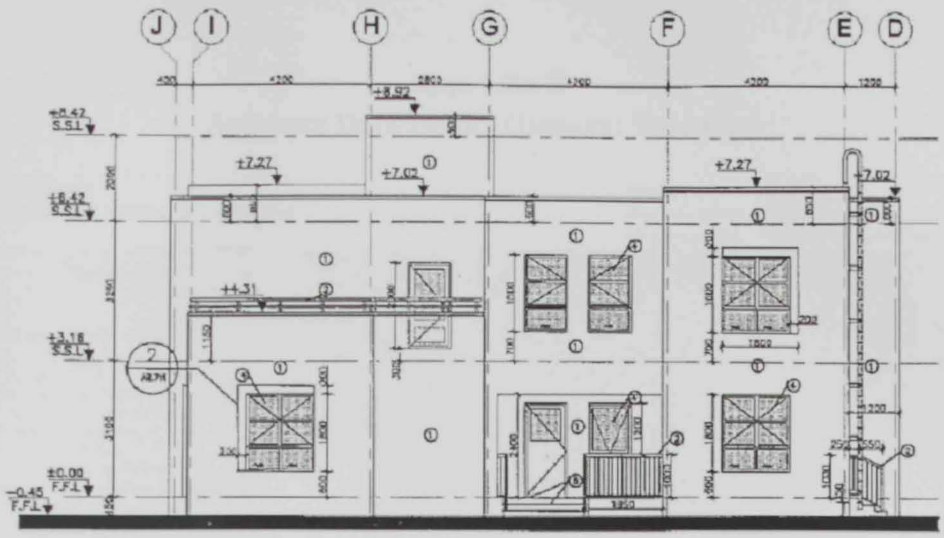
Al Falah Villa First Floor Plan



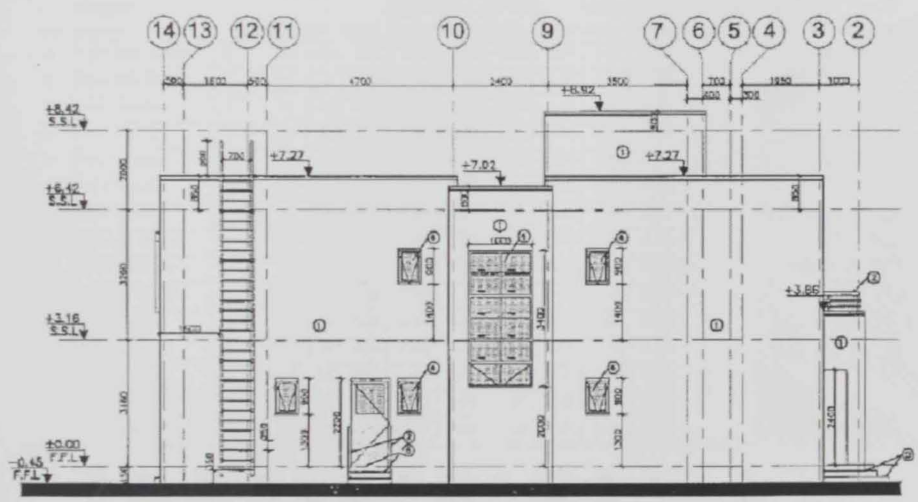
Front Elevation



Right Side Elevation

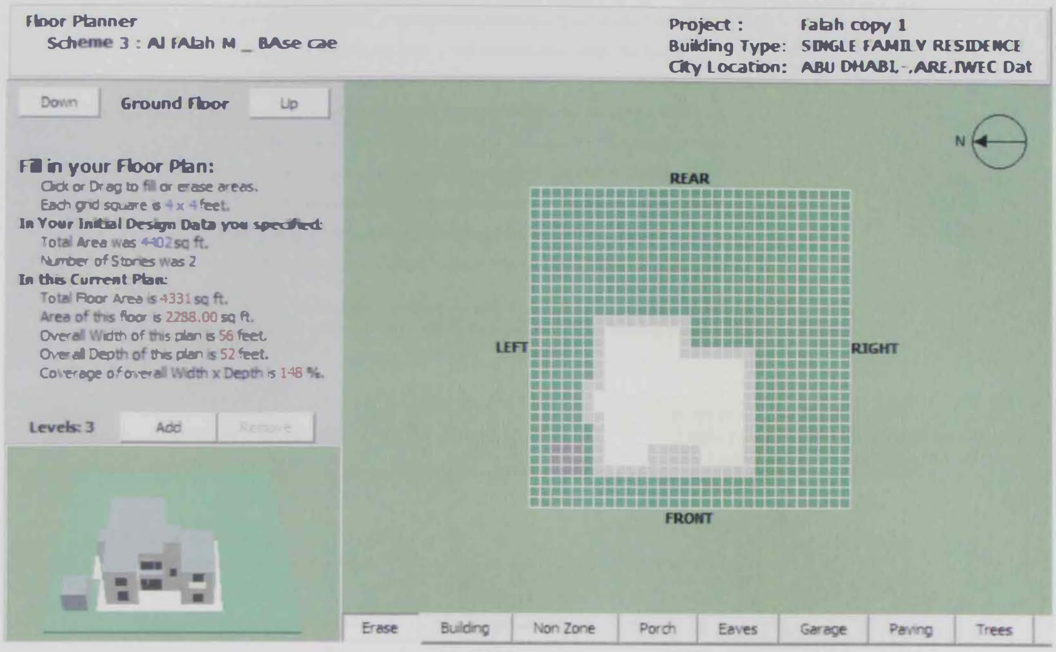


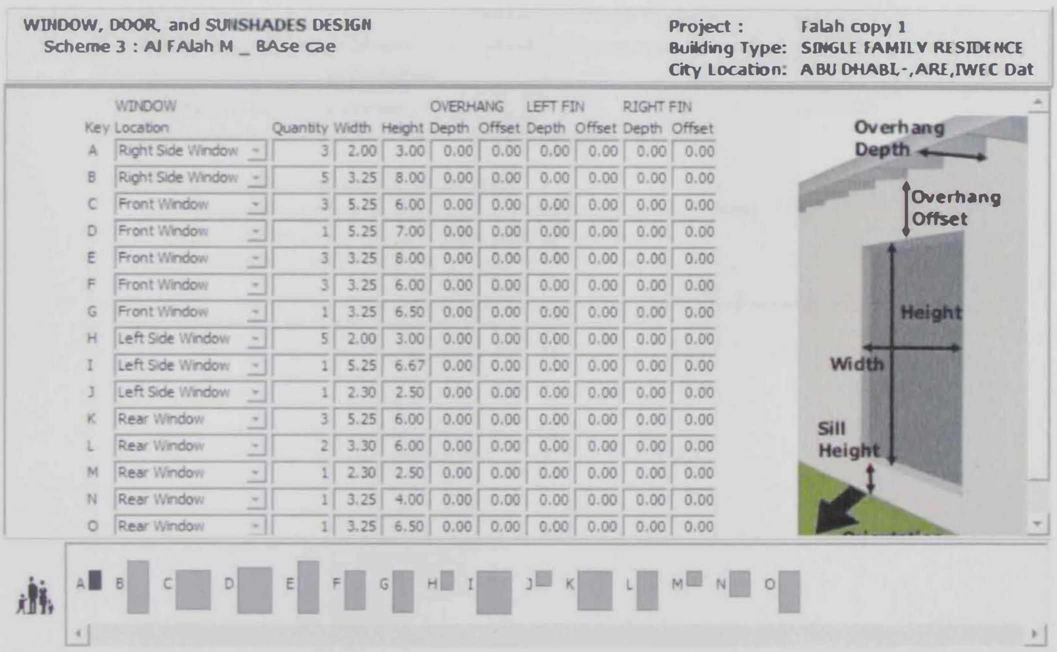
Rear Elevation



Left Side Elevation

Appendix B
Software Data Inputs Outputs; Base Case





Key	WINDOW Location	Quantity	Width	Height	OVERHANG Depth	OVERHANG Offset	LEFT FIN Depth	LEFT FIN Offset	RIGHT FIN Depth	RIGHT FIN Offset
A	Right Side Window	3	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
B	Right Side Window	5	3.25	8.00	0.00	0.00	0.00	0.00	0.00	0.00
C	Front Window	3	5.25	6.00	0.00	0.00	0.00	0.00	0.00	0.00
D	Front Window	1	5.25	7.00	0.00	0.00	0.00	0.00	0.00	0.00
E	Front Window	3	3.25	8.00	0.00	0.00	0.00	0.00	0.00	0.00
F	Front Window	3	3.25	6.00	0.00	0.00	0.00	0.00	0.00	0.00
G	Front Window	1	3.25	6.50	0.00	0.00	0.00	0.00	0.00	0.00
H	Left Side Window	5	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
I	Left Side Window	1	5.25	6.67	0.00	0.00	0.00	0.00	0.00	0.00
J	Left Side Window	1	2.30	2.50	0.00	0.00	0.00	0.00	0.00	0.00
K	Rear Window	3	5.25	6.00	0.00	0.00	0.00	0.00	0.00	0.00
L	Rear Window	2	3.30	6.00	0.00	0.00	0.00	0.00	0.00	0.00
M	Rear Window	1	2.30	2.50	0.00	0.00	0.00	0.00	0.00	0.00
N	Rear Window	1	3.25	4.00	0.00	0.00	0.00	0.00	0.00	0.00
O	Rear Window	1	3.25	6.50	0.00	0.00	0.00	0.00	0.00	0.00

Walls
Scheme 3 : Al FAlah M _ BAse cae

Project : Falah copy 1
Building Type: SINGLE FAMILY RESIDENCE
City Location: ABU DHABI,-,ARE,IWEC Dat

Walls

- ( ) Stucco or Face Brick on 2x4 Wood Studs at 16" with Plaster Board Interior
- ( ) Wood or Vinyl Siding on 2x4 Wood Studs at 16", Plaster Board Interior
- ( ) Stucco or Face Brick on 2x6 Wood Studs at 24", with Plaster Board Interior
- ( ) Wood or Vinyl Siding on 2x6 Wood Studs at 24", Plaster Board Interior
- ( ) Stucco, Vinyl, or Wood, 1"+Polystyrene,Plywood,2x4 Wood Studs at 16", Plaster Board
- ( ) Stucco, Vinyl, or Wood, 1"+Polystyrene,Plywood,2x6 Wood Studs at 24", Plaster Board
- ( ) Stucco on 4-1/2" SIPS Panels (OSB, 3-5/8"+Polystyrene, OSB), Plaster Board
- ( ) Stucco on 8" Hollow Concrete Block, +Insulation,2x4 Stud Wall, Plaster Board (acts like low mass)
- (•) Stucco on 8" Hollow Concrete Block, Insulation filled cores, Exposed or Plastered
- ( ) Wood or Vinyl Siding, Foil, Air Space, 8" Hollow Concrete Block, Exposed or Plastered
- ( ) Stucco, 2"+Polystyrene on 8" Hollow Concrete Block, Exposed or Plaster Board
- ( ) Stucco, 2"+Polystyrene on 5" Solid Concrete or Block, Exposed or Plaster Board
- ( ) Stucco, 9" Insulated Foam Forms Concrete filled, Plaster Board Interior
- ( ) Solid 8"Masonry Wall, uninsulated, Exposed Inside and Out (does not meet code)

Note: "+" means thickness can increase if required by the Insulation screen or to meet Local Energy Code
Other Assemblies calculated by hand can be loaded on the Surface Area screen (use Time Lag and Decrement from similar walls here)

Insulation
Scheme 3 : Al FAlah M _ BAse cae

Project : Falah copy 1
Building Type: SINGLE FAMILY RESIDENCE
City Location: ABU DHABI,-,ARE,IWEC Dat

Level of Insulation:

( ) No Insulation: House Built pre-Sixties	(Wall R=0,Ceiling R=0, Floor R=0)
( ) Insulated Attic Only	(Wall R=0,Ceiling R=19, Floor R=0)
( ) Insulated Attic and Raised Floor	(Wall R=0,Ceiling R=19, Floor R=13)
( ) Little Insulation: Built before Energy Code in 1978	(Wall R=7,Ceiling R=11, Floor R=0)
(•) Early Energy Code	(Wall R=11,Ceiling R=19, Floor R=11)
( ) Current Energy Code (2005) for Climate Zone 15	(Wall R=21,Ceiling R=38, Floor R=19)
( ) Insulation Upgrade to 1.5 times Current Code	
( ) Super Insulation to 2 times Current Code	
( ) Current Energy Code with Heavy Mass Walls	(Wall R=4.76,Ceiling R=38, Floor R=0)

Reflective Foil Radiant Barriers (in Attics only)

- ( ) Radiant Barrier installed in Attic (shiny surface facing into vented attic above insulation in ceiling)
  or in Flat Roof (shiny surface facing into a vented air space above insulation)
- (•) No Radiant Barrier in Attic or Flat Roof (or upstairs is an occupied unit: see Roof screen)

R-Values in Current Energy Code are for insulation installed between wood framing members (Total assembly R-Values will be less)
Note: In this Climate Zone 15, the Code Package C and D requires a Radiant Barrier in Attics

Roof
Scheme 3 : Al FAlah M _ BAse cae

Project : Falah copy 1
Building Type: SINGLE FAMILY RESIDENCE
City Location: ABU DHABI, -ARE,IWEC Dat

Roof Construction :

- ○ No Heat Loss through ceiling because upstairs is another heated unit
- ○ Cool Roof Flat or Low Sloped (less than 9.5 degrees)
- ○ Cool Roof Sloped, Naturally Ventilated Attic, Light Weight Shingles (less than 5 lb/sq ft)
- ○ Cool Roof Sloped, Fan Vented Attic, Light Weight Shingles (less than 5 lb/sq ft)
- ○ Cool Roof Sloped, Naturally Vented Attic, Heavy Weight Tiles (5 lb/sq ft or more)
- ○ Cool Roof Sloped, Fan Vented Attic, Heavy Weight Tiles (5 lb/sq ft or more)
- ◉ Default Flat or Low Sloped Roof, (less than 9.5 degrees)
- ○ Default Sloped Roof, Naturally Ventilated Attic, Light Weight Shingles (less than 5 lb/sq ft)
- ○ Default Sloped Roof, Fan Vented Attic, Light Weight Shingles (less than 5 lb/sq ft)
- ○ Default Sloped Roof, Naturally Vented Attic, Heavy Weight Tiles (5 lb/sq ft or more)
- ○ Default Sloped Roof, Fan Vented Attic, Heavy Weight Tiles (5 lb/sq ft or more)

Cool Roofs have higher reflectance which means they absorb less solar radiation, and slightly higher thermal emittance which means they re-radiate heat to the sky during both day and night.
In this climate zone, attics must have a Reflective Foil Radiant Barrier on the underside of the roof exposed to attic air, to meet the Energy Code's Prescriptive Package C and D (see Basic Insulation screen).
All Roofs have Plaster Board Ceilings and Wood Joists with Insulation between.
Attic Fans have a thermostat so only run when needed.
Other Assemblies calculated by hand can be loaded on the Surface Area screen (use Time Lag and Decrement from similar roofs here)

Ventilation Cooling
Scheme 3 : Al FAlah M _ BAse cae

Project : Falah copy 1
Building Type: SINGLE FAMILY RESIDENCE
City Location: ABU DHABI, -ARE,IWEC Dat

INDOOR AIR VELOCITY FOR COOLING:

- ◉ Ignore any Cooling from Air Motion (omit Ceiling fans and Natural Ventilation, but there can be a Whole House fan)
- ○ Gentle Air Velocity: air motion up to 160 FPM (will feel effectively 4.6°F cooler) good for sedentary activities
- ○ Strong Air Velocity: air motion up to 300 FPM (will feel effectively 6.6°F cooler) might rustle newspaper

Comfort is based on the Effective Temperatures from the PMV Model as defined in ASHRAE Standard 55 (see Help)

NATURAL VENTILATION:

- ◉ WINDOWS remain SHUT so No Natural Ventilation (may have a continuously running vent fan for required indoor air quality)
- ○ WINDOWS and DOORS are manually OPENED if cooling is needed and if Outdoor Temperature is below Comfort High;

Cooling Efficiency improves if there is more window opening area, if openings are on opposite walls, or at least on side walls, and if there are multiple stories, or better yet an open atrium, and with higher outdoor wind speeds.

FAN FORCED VENTILATION:

- ◉ No Fans for Comfort Cooling (but has a Continuously Running Fresh Air Fan for Indoor Air Quality: see HVAC screen)
- ○ Small Whole House Fan (5 Air Changes/hour): assume gentle air velocity, Smart Thermostat controlled exhaust fan
- ○ Large Whole House Fan (20 Air Changes/hour): assume strong air velocity, Smart Thermostat controlled exhaust fan
- ○ Ceiling Fans: Smart Thermostat and Occupant Sensors (means only one fan running per occupant)
- ○ Ceiling Fans: Smart Thermostat and Manually Switched (means at least 1.5 fans running per occupant)
- ○ Special Test Case: Whole House Fan runs from 6pm to 7am, otherwise Air Conditioning if needed (but no furnace exists)

Continuously Running Fresh Air Fans and Heat Recovery Ventilators can be removed on the HVAC System screen.
CLOTHING RATING (clo), ACTIVITY RATING (met), and COMFORT MODEL explained in Help
Assume a Smart Fan Thermostat tries to keep Winter temperature near Comfort High and Summer Temperature near Comfort Low, and switches to Winter mode when Monthly Average Outdoor Temperature falls below Comfort Low (i.e. 70.F)

Infiltration
Scheme 3 : Al FAlah M _ BAse cae

Project : Falah copy 1
Building Type: SINGLE FAMILY RESIDENCE
City Location: ABU DHABI,-,ARE,IWEC Dat

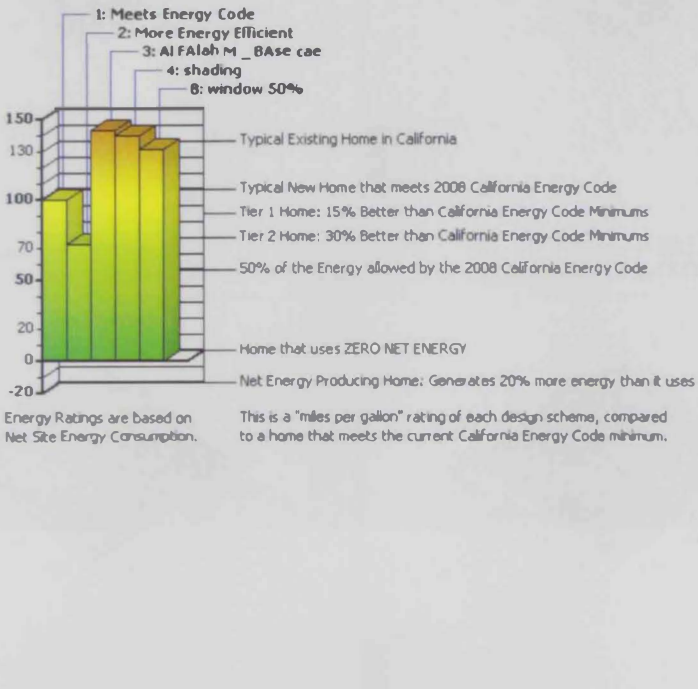
INFILTRATION: Building Wrap, and Duct Sealing

- ( ) Very Poorly Sealed Older Building (estimated at 6.0 SLA, Specific Leakage Area: see Help for definition)
- ( ) Poorly Sealed Early Code Building, 1978 to 2006 (estimated at 4.9 SLA, Specific Leakage Area)
- ( ) Ducted HVAC System but without special duct sealing (4.3 SLA, Specific Leakage Area)
- ( ) DEFAULT STANDARD DESIGN with a ducted HVAC System with sealed ducts (3.8 SLA)
- ( ) Add Air-Retarding House Wrap to Standard Design, all joints lapped and taped (3.3 SLA)
- (•) Non-ducted HVAC System, or all ducts are inside the building's insulated envelope (3.2 SLA)
- ( ) Sealed Building: Unusually Tight Construction requires Continuous Ventilation Fan for Indoor Air Quality (1.5 SLA):

Note: If Diagnostic Testing (Blower door) is used, the actual measured SLA can be entered on the HVAC screen
Note: All new California homes require a continuously running ventilation fan for fresh air (to meet ASHRAE 62.2).
Elsewhere this amount of fresh air could be provided by infiltration and if necessary by occupants who open windows as needed.

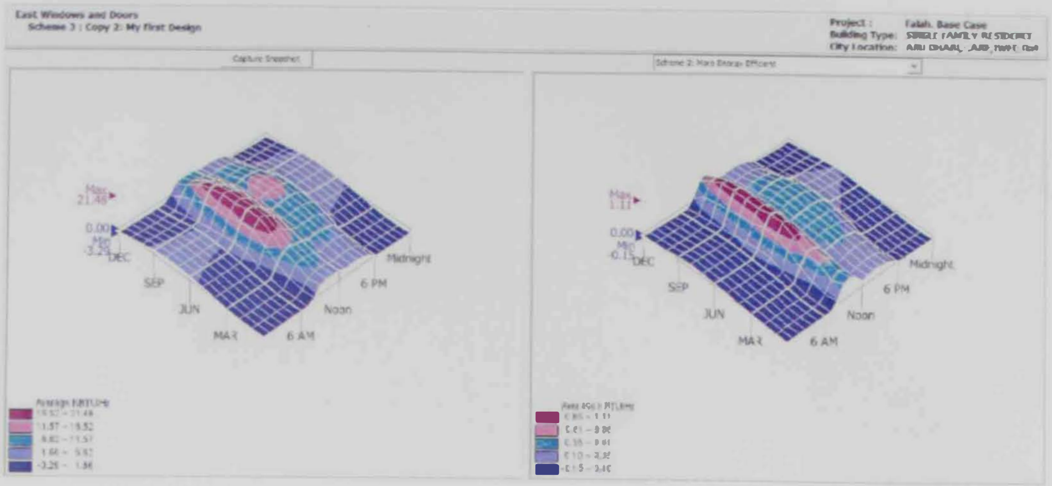
Home Energy Rating
Scheme 3 : Al FAlah M _ BAse cae

Project : Falah copy 1
Building Type: SINGLE FAMILY RESIDENCE
City Location: ABU DHABI,-,ARE,IWEC Dat



Energy Ratings are based on Net Site Energy Consumption.

This is a "miles per gallon" rating of each design scheme, compared to a home that meets the current California Energy Code minimum.


East Windows and Doors
Scheme 3 : Copy 2: My First Design
Project : Falah. Base Case
Capture Snapshot
Max 21.48
0.00
Min -3.25
DEC
SEP
JUN
MAR
6 AM
Noon
6 PM
Midnight
Max 1.11
0.00
Min -0.15
DEC
SEP
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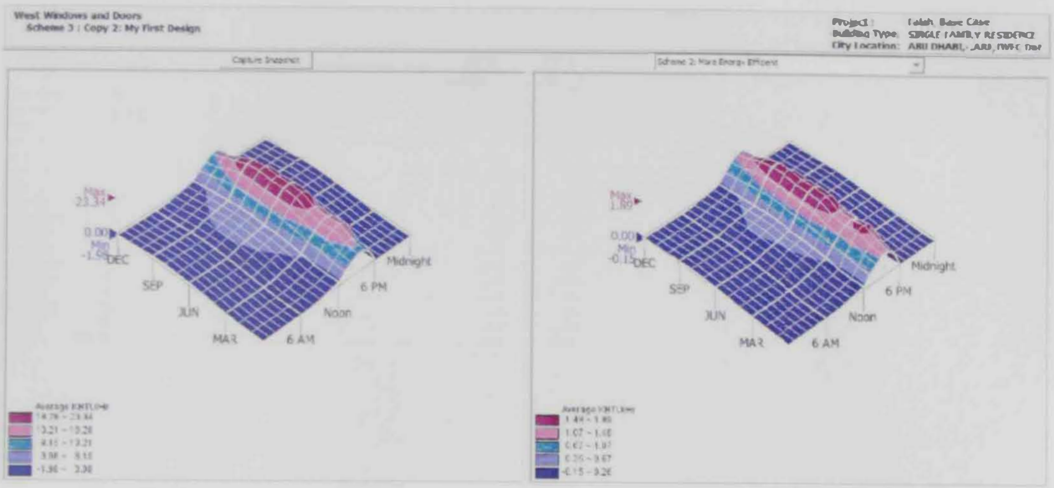
MAR
6 AM
Noon
6 PM
Midnight


West Windows and Doors
Scheme 3 : Copy 2: My First Design
Project : Falah. Base Case
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0.00
DEC
SEP
JUN
MAR
6 AM
Noon
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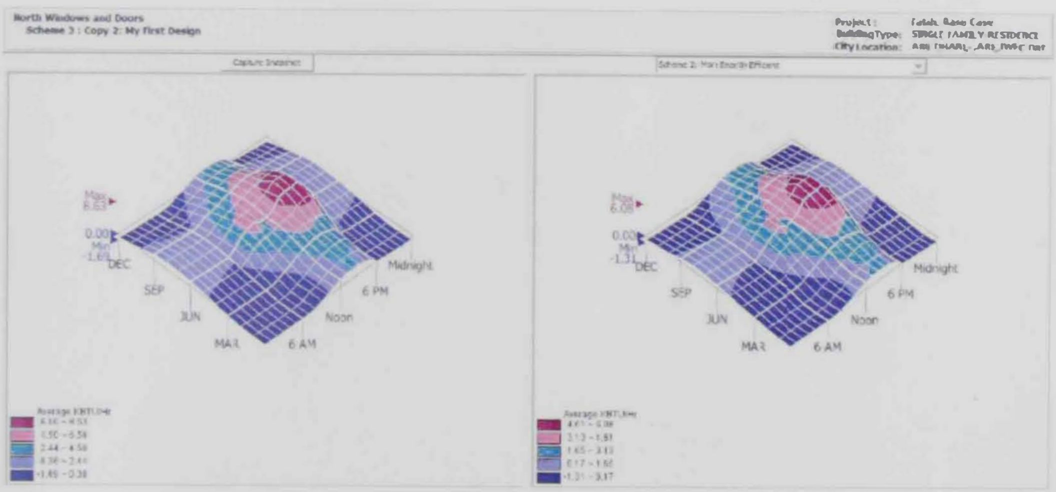
SEP
JUN
MAR
6 AM
Noon
6 PM
Midnight


North Windows and Doors
Scheme 3 : Copy 2: My First Design
Project : Falah. Base Case
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0.00
DEC
SEP
JUN
MAR
6 AM
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6 PM
Midnight
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DEC
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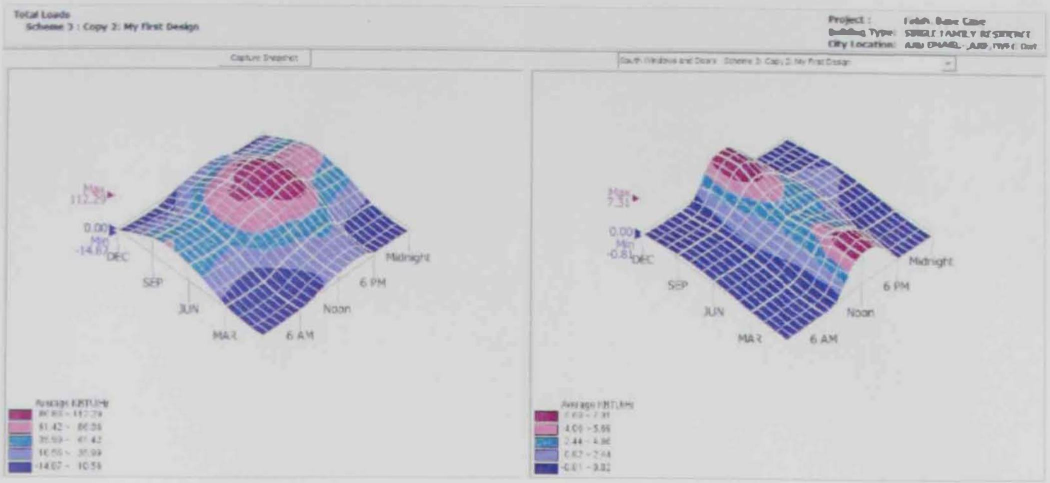
MAR
6 AM
Noon
6 PM
Midnight


Total Loads
Scheme 3 : Copy 2: My First Design
Project :
Building Type:
City Location:
Max
112.29
0.00
Min
-14.87
DEC
SEP
JUN
MAR
6 AM
Noon
6 PM
Midnight
Max
7.31
0.00
Min
-0.81
DEC
SEP
JUN
MAR
6 AM
Noon
6 PM
Midnight
Average KBTU/Hr
Average KBTU/Hr


Project :

اشارت النتائج في المرحلة النهائية من التقييم العملي توفير في استهلاك الطاقة الكهربائية السنوي تراوح بين حوالي 6% في المبنى الموجه الى الشرق و حوالي 13% من استهلاك المباني المواجهة للغرب.

الجدير بالملاحظة في نتائج الاختبار العملي للاداء الحراري لانظمة النوافذ المحسنة هو الأداء الحراري المتقارب مع التوجيه المتغير للمبنى و الذي يمنح توفير في الطاقة الى جانب المرونة في التخطيط العمراني للتجمعات السكنية الحكومية.

الملخص

تعتبر دولة الامارات العربية المتحدة من اعلى الدول استهلاكا للطاقة من حيث حصة الفرد. و يعتبر قطاع المباني المستهلك الأكبر للطاقة حيث انه المسول عن استهلاك قرابة 70% من الطاقة التي تستخدم بغرض تكيف الهواء داخل المباني. خلال العقود القليلة الماضية قامت حكومة الامارات العربية المتحدة بتدشين العديد من برامج الإسكان التي تلبي احتياجات المواطنين و في الاوانه الأخيرة تراعي توفير استهلاك الطاقة.

تهدف هذه الدراسة الى تحقيق الأداء الحراري الأمثل للنوافذ مع التوجيه المتغير للمباني في مشاريع الإسكان الحكومية. من المعلوم ان توجيه المباني في مشاريع الإسكان يكون خاضعا للتخطيط العمراني للمناطق السكنية بدون الاخذ بعين الاعتبار التاثير الحراري لاختلاف توجيه المباني و تاثيره على استهلاك الطاقة.

في بداية هذه الدراسة تمت مراجعة للتطور التاريخي للاسكان في الامارات العربية المتحدة. ثانيا تمت مراجعة و عرض القواعد المثلي لتصميم وتحسين الأداء الحراري للنوافذ.

لاحقا, تم اختيار نموذج لمساكن المواطنين من اجل اخضاعه للاختبار و التحسين. هذا الاختيار تم بناء على دراسة مفصلة ومستفيضة لمجمع الفلاح السكني في أبو ظبي. و لقد شملت الدراسة و التحليل المخطط العام للمجمع, نماذج المساكن , مواد الانشاء و تصميم النوافذ.

المرحلة الأولى من الاختبار العملي لنموذج المساكن تم فيها تقييم التاثير الحراري لتوجيه المباني. تم الاختبار العملي باستخدام برنامج محاكاة لتقييم الأداء الحراري يسمى Home Energy Efficient Design (HEED).

اشارت النتائج اختلاف الأداء الحراري و بالتالي معدلات استهلاك الطاقة الكهربائية للمبنى باختلاف توجيه المبنى . هذا الاختلاف كان بواقع 9.7% زيادة في استهلاك الطاقة الكهربائية في المباني الموجهة للغرب عن المباني الموجهة للشرق, و حوال 3% زيادة في استهلاك الطاقة الكهربانية عن المباني المواجهة للشمال و الجنوب.

المرحلة الثانية من الاختبار العملي تناولت تاثير تحسين العناصر المكونة للنوافذ مثل الزجاج, الاطار, التظليل الخارجي (كاسرات الشمس) على الأداء الحراري للنوافذ مع الاتجاهات المختلفة.

المرحلة الأخيرة من الاختبار و التقييم العملي تم تصميم نظامين نوافذ باستخدم نتائج المرحلة الثانية باختيار المكونات ذات النتائج الافضل.

النظام الأول اشتمل على زجاج (double- tinted squared Low E) مع اطار (Vinyl). بينما اشتمل النظام الثاني على زجاج (double-tinted Low E) مع اطار (Vinyl) و تركيب كاسرة شمس خارجية على شكل شرائح متحركة اليا (Automated slatted Blinds).

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